PILOTS' AND MECHANICS' AIRCRAFT INSTRUMENT MANUAL

By

G. C. DeBAUD

CAPTAIN, UNITED STATES ARMY AIR FORCE

Former Aeronautical Engineering Officer in Charge of R.C.A.F. Instrument Repair Base; Approved C.A.A. Ground Instructor on Aircraft Instruments; formerly President and Chief Instructor at American and DeBaud Schools of Aircraft Instruments

THE RONALD PRESS COMPANY NEW YORK

Third Printing, June, 1943

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

This textbook on aircraft instruments is designed to meet the requirements of thorough, systematic courses in technical and aviation schools and the needs of those who wish to acquire a complete understanding of instruments but who do not have the opportunity for an instructor's guidance. It follows a method of presentation developed from many years of experience in instructing and training men in the use and maintenance of aircraft instruments—a method which, the author believes, gives a thorough knowledge of all types of instruments—flight, navigation, and engine—in the shortest time, and with the minimum of effort. To that end, while the subject matter is fully adequate, it has been made as simple and direct as possible, unencumbered with extreme technical detail interesting to the specialist on a particular instrument but more confusing than helpful to the pilot or mechanic.

Instruments may rightly be called the "brains" of the aircraft, for it is upon their indications that the pilot depends for flight safety and the efficient operation of his plane. Instruments and instrument flying are a major branch of aviation and all personnel are required to have knowledge, in varying degrees, of this important branch. The time is past when a superficial understanding of simply the general purpose of the instruments was sufficient. Today a thorough knowledge of instruments and their use is a necessity and a distinct step in advancement for pilots, groundmen, mechanics, and in fact all engaged in aviation. The pilot and flying student should find the manual of much help in the preparation now necessary for the government pilot rating tests. The groundman and mechanic will find it of aid in passing the required examinations for the mechanics' license and ratings.

The chapters of the book are so arranged that progressively the user will fully understand the construction of each instru-

ment, its purpose and necessity, the errors which might occur and their remedies, and the instrument's installation and maintenance. To help understand the written part of the text more clearly, numerous photographs, working charts, and diagrams have been provided.

In order that the book might be accurate in all details, modern, and complete, the advice and cooperation of various instrument manufacturers, aircraft organizations and personnel have been sought. Most generous help in time and material has been given by Manning, Maxwell and Moore, Inc. (Ashcroft Instruments); The Lewis Engineering Company; Pioneer Instrument Division of Bendix Aviation Corporation; Kollsman Instrument Division of Square D Company; Cambridge Instrument Company; The Liquidometer Corporation; Western Electric Company; Northern Electric Company; Sperry Gyroscope Company, Inc.; Bausch and Lomb Optical Company; Lord Manufacturing Company; Link Aviation Devices, Inc.; Weems System of Navigation; Douglas Aircraft Company, Inc.; American Airlines, Inc.; Pan American Airways; Lockheed Aircraft Corporation; United Airlines; Transcontinental and Western Air, Inc.; Beech Aircraft Corporation; and the United States Weather Bureau. The author desires to express his sincere appreciation to all these organizations for their helpful cooperation.

Special mention and thanks are also due Lieutenant Commander P.V.H. Weems and Mr. Charles A. Zweng for their unstinting aid.

G. C. DeBaud

January, 1942

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PILOTS' AND MECHANICS' AIRCRAFT INSTRUMENT MANUAL

CHAPTER 1

OIL PRESSURE GAUGE

The oil pressure gauge serves the purpose of indicating to the pilot the condition of the motor. Of primary importance before take-off are the indications of the oil pressure gauge, engine temperature thermometer and the tachometer. The oil pressure gauge shows the pressure under which the oil is being fed to the moving parts of the engine. The engine temperature thermometer indicates the correct temperature of the engine for the take-off. The known ground revolutions per minute (r.p.m.) of the engine are checked by the tachometer. The failure of any one of these indications will forestall the take-off.

Although the name has never been applied, this group of instruments might reasonably be called the "Ground Primary Group" much in the same manner as the air-speed, turn and bank and rate of climb are known as the "Flight Primary Group."

In flight, the lowering or complete loss of indication of the oil pressure gauge may mean the failure of the oil pump, insufficient oil, leaking connections in the line or a ruptured line, any one of which will cause engine failure. Usually a rise in temperature of the engine temperature thermometer accompanies these indications. If the engine temperature thermometer does not show an increase in temperature, the oil pressure gauge may have failed, but this rarely occurs since the Bourdon spring type gauges are the sturdiest of all instruments.

Operation

As oil is forced to the various parts of the engine under pressure, it is also fed into the connecting metallic line leading to the fitting at the back of the instrument as shown in Figure 4. The oil enters the Bourdon spring base, Figure 2, and fills the Bourdon spring. The applied pressure will move the spring

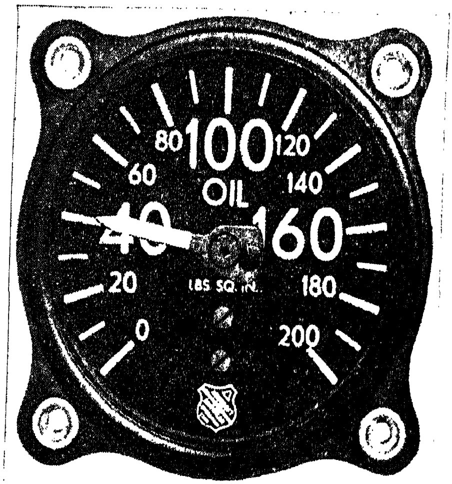


Figure 1. Ashcroft Oil Pressure Gauge Type 6710-17

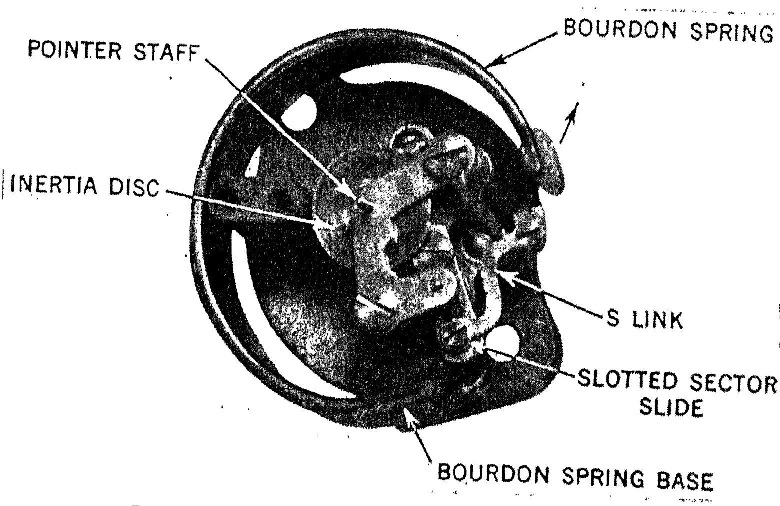


Figure 2. Ashcroft Oil Pressure Gauge Mechanism

outward as shown by the arrow. Since the spring is attached to the mechanism linkage, its movements will rotate the pointer staff on which rests the indicating pointer. The pointer moves across the dial indicating oil pressure in pounds per square inch.

Possible Causes of Failure or Inaccuracy

A leak or failure at Bourdon tube renders gauge inoperative and necessitates replacement of Bourdon assembly.

"Set" in Bourdon tube caused by overpressure may be corrected by recalibration if Bourdon tube is not visibly distorted. Distorted tube should be replaced with new Bourdon assembly.

Excessive friction in the gauge resulting from dirt or wear. Examine movement gear teeth, movement bearings, and link bearings carefully. Clean or replace.

An indication too high may be caused by: (a) oil temperature too low, (b) oil cold or too heavy, (c) gauge out of calibration.

An indication too low may be caused by: (a) oil temperature too high, (b) oil too light or thin; (c) gauge out of calibration.

Gauge failing to register indicates: (a) insufficient oil, (b) plugged connecting line, (c) defective gauge.

Test Apparatus

The apparatus is of the dead weight type and is provided with two pistons and two sets of weights. The lighter piston is stamped "1/5 lb. Avdp.—1 lb. sq. in." and is used for calibrating gauges from 0 to 10 lb. pressure. It is used with five small weights, allowing graduations of 1 lb. increments. The large piston is stamped "1 lb. Avdp.—5 lbs. sq. in." and is used for calibrating gauges up to 200 lb. pressure. It is used with eleven weights, allowing graduations of 5 lb. increments. The weights are a circular nesting type, accurately calibrated.

A set of six adapters is used for gauge attachments. This set includes 1/8", 1/4", 3/8" pipe thread, male; 1/8", 1/4" pipe thread, female; and an angle adapter 7/16-20 U.S.S.

Calibrating pressures are developed in the oil reservoir by actuating a screw plunger. The tester incorporates a cut-out valve, a suitable fixture for gauge mounting, and an oil drain.

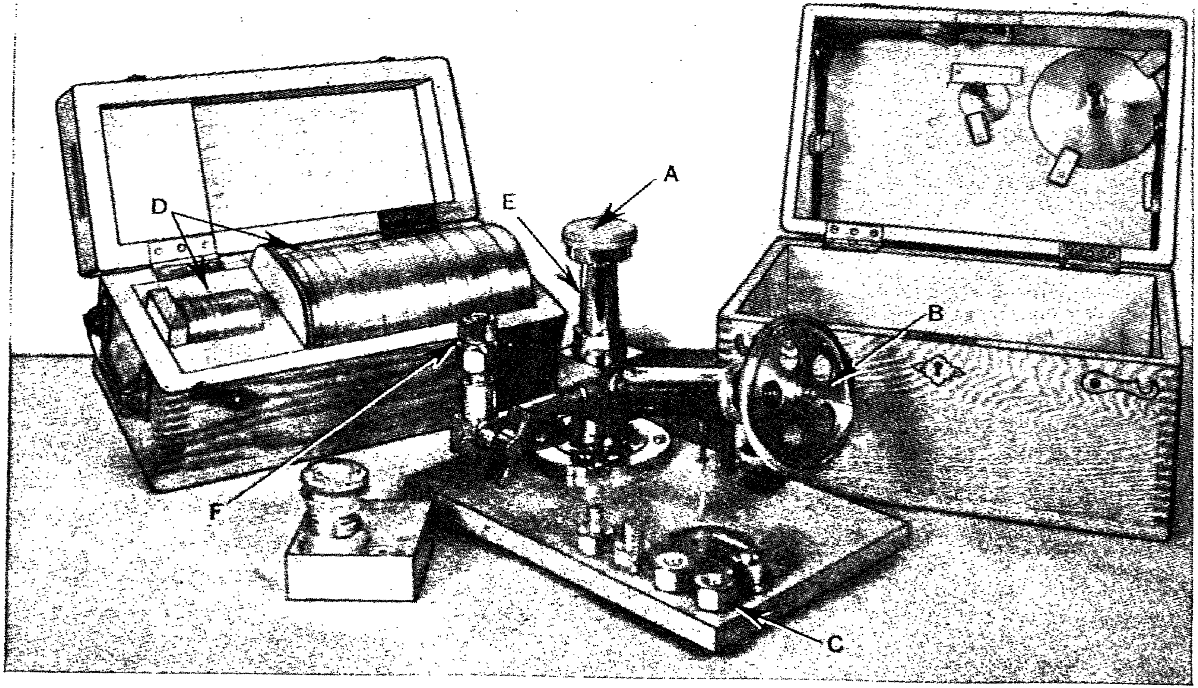


Figure 3. Pioneer Gauge Test Apparatus
(Pioneer Instrument Division of Bendix Aviation Corp.)

A—Weight Platform
B—Hand Wheel
C—Adapters
D—Weights
E—Piston
F—Connect Gauge under Test Here

Directions for Tests

Fill the gauge test apparatus with oil according to instructions furnished with apparatus. Mount the instrument at (F), select correct weights (D), and place on weight platform (A). Operate hand wheel till weight platform lifts slightly. The piston with the weight tray will then exert pressure on gauge under test of exactly the number of pounds per square inch as is stamped on the weight. The piston should be revolved slowly during the tests to eliminate frictional errors. The distance between the upper edge of the overflow cap of the cylinder and the piston tray should not exceed 1″. After tests, release pressure by means of the hand wheel. Weights should never be removed until after pressure is released.

Calibration

Calibration adjustments are made by:

(a) Positioning of link in slotted sector slide to provide pointer movement corresponding to "range" of dial. Moving link in increases pointer movement.

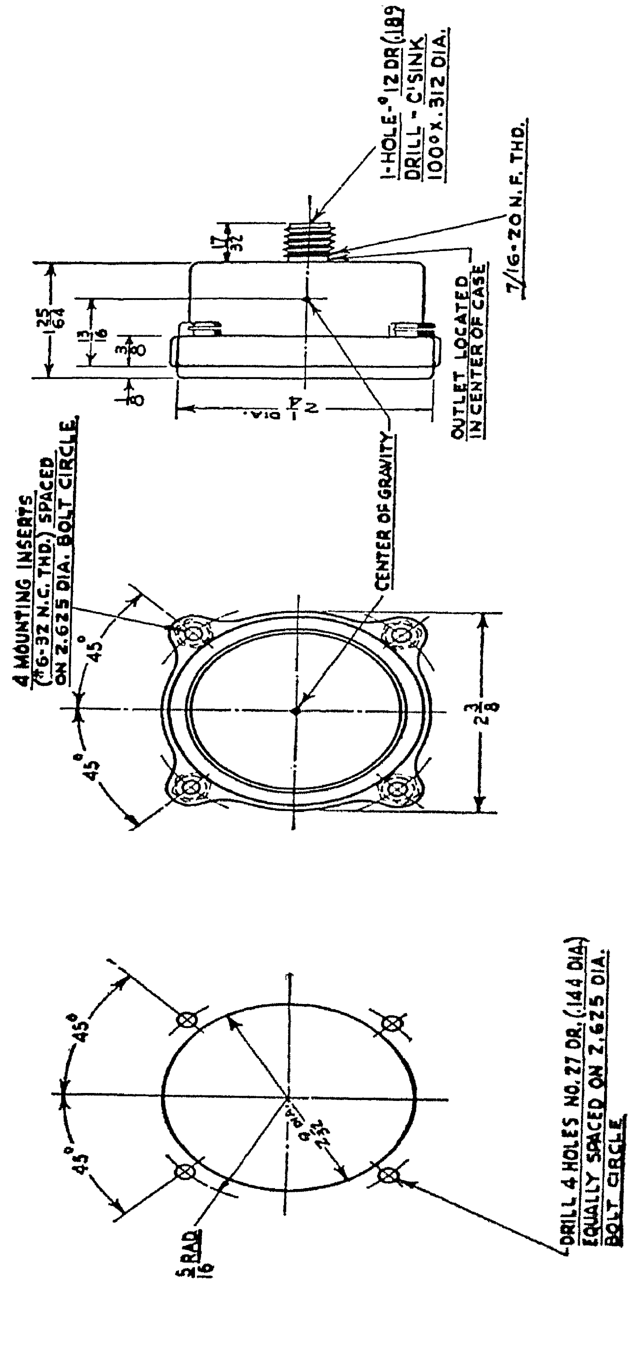
(b) Varying length of S-shaped link to give curve characteristics which conform to intermediate scale calibration marks. Lengthening link makes pointer movement progressively less for increasing applied pressures.

Calibration tolerances are given in the following table:

Pressure lbs./sq. in.	Tolerance
0	2
50	3
100	3
150	5
200	5

Installation

The instrument panel cut-out is shown at the left. The outlet to which the pressure line is connected is shown at the right. The pressure line should be clamped to rigid members of the airplane at frequent intervals throughout its length. The oil


1-HOLE-#12 DR (.189) DRILL - C'SINK 100° X .312 DIA.
7/16-20 N.F. THD.
OUTLET LOCATED IN CENTER OF CASE
17/32
1 25/64
13/16
3/8
1/8
2 1/4 DIA.
CENTER OF GRAVITY
4 MOUNTING INSERTS (#6-32 N.C. THD.) SPACED ON 2.625 DIA. BOLT CIRCLE
45°
45°
2 3/8
45°
45°
2 9/32 DIA.
5/16 RAD
DRILL 4 HOLES NO. 27 DR. (.144 DIA.) EQUALLY SPACED ON 2.625 DIA. BOLT CIRCLE

ion D Oi G

pressure gauge and the engine temperature thermometer should be mounted adjacent to each other. If the panel is shock-mounted a short flexible length of oil resisting rubber tubing should be connected into the line at the instrument.

The instrument is mounted by using four #6-32 screws.

CHAPTER 2

FREE AIR THERMOMETER

The outside air thermometer is designed to indicate the temperature of the air through which the aircraft is passing. This temperature indication is used to warn of possible icing conditions and provide the necessary temperature correction to altimeter, air-speed, and other flight and engine performance curves.

Operation

The thermometer is a "vapor pressure" type, and hence essentially a pressure measuring instrument. It comprises a bulb, capillary, and Bourdon spring system partially filled with a volatile liquid such that the junction of liquid and vapor phase always remains in the bulb. The vapor pressure corresponding to the bulb temperature is transmitted through the capillary tubing to the Bourdon spring in the instrument. Since the vapor pressure of a liquid is not directly proportional to temperature, approximate uniformity of dial graduations is obtained by progressively "retarding" the deflection of the Bourdon spring by retard stops placed about the circumference of the spring. The indicating mechanism in the case consists of the Bourdon spring and a precision pinion and sector movement, which transmits deflection of Bourdon spring to thermometer pointer.

Possible Causes of Failure or Inaccuracy

LEAK IN THERMOMETER SYSTEM. Renders thermometer inoperative; pointer will read approximately —40° C. at room temperature. Replace with new thermometer system. *Note:* The large majority of failures due to leaking thermometer systems are caused by the following factors:

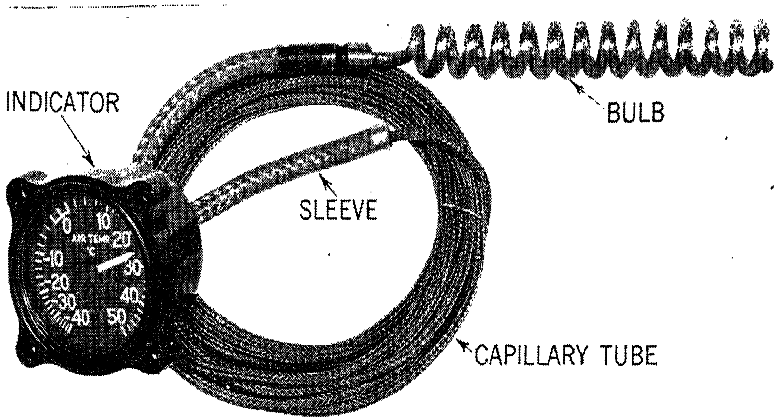


Figure 5. Ashcroft Free Air Thermometer Type 6648

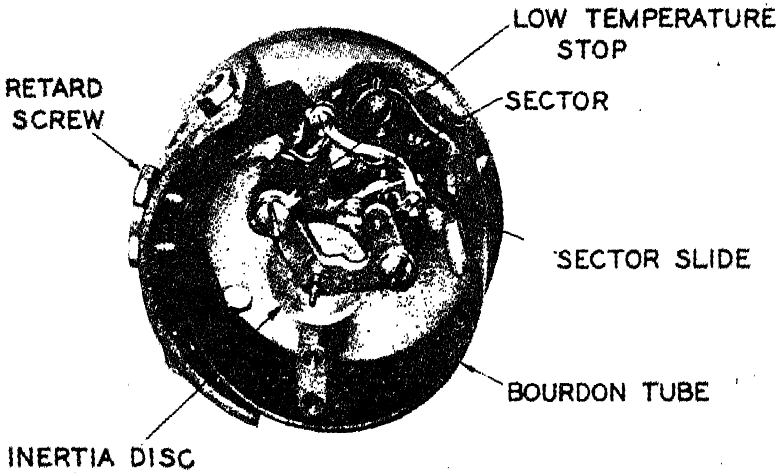


Figure 6. Gauge Mechanism of Free Air Thermometer

(a) Chafing of the capillary tubing on parts of the airplane structure so that it wears through and the tubing is broken.

(b) Chafing of the tubing within its own reinforcing sleeves at the instrument or bulb. These sleeves are not designed to absorb vibration from the tube to the instrument but are used to insure the proper radius of turn of the tube into the bulb or instrument.

Failures as listed under (a) may be eliminated by proper clamping of the capillary tubing to the aircraft structure and failures as listed under (b) may be eliminated by clamping the capillary tubing just adjacent to the reinforcing sleeves at the bulb and at the instrument to the same structural member to which the bulb or instrument is attached. This eliminates the possibility of vibration of the capillary tubing within its reinforcing sleeves. If it is impossible to install the tubing as mentioned in the foregoing, the capillary tubing should be securely taped at its entrance into the reinforcing sleeve if the tubing is clamped to a member having a different vibrational characteristic than member to which instrument or gauge is attached.

Capillary Tubing Plugged. Thermometer either inoperative or very sluggish. Replace with new system.

Excessive Friction. If thermometer is not dead, rap instrument sharply and note if pointer assumes correct reading. If so, there is excessive friction or lost motion resulting from corrosion or wear. Examine link bearings and movement carefully. Replace if necessary.

Loose Parts. If thermometer responds to changes in bulb temperature and does not appear to have excessive friction as outlined above, an incorrect indication may be caused by loose parts. Examine "retard" screws, adjustable slide or movement sector, links, pivot screws, etc.

Testing Procedure

To test the outside air thermometer it is necessary to have a "cooling bath," a "hot bath" and master gauges. The "cooling

bath" may be a trough of Prestone cooled by a refrigeration system and the "hot bath" may be similar to the testing apparatus used for the engine thermometer.

The bulb is submerged in the "cooling bath" whose temperature is gradually decreased until the maximum temperature of −40° C. is reached. Readings are taken from the instrument and compared with the master at 10° intervals. The instrument is then removed and the system allowed to assume room temperature.

With water in the "hot bath" at room temperature, the bulb is submerged and the heating system turned "on." As the temperature increases, readings are again taken and compared with the master gauge.

The instrument should be tested in a vertical upright position and should be lightly tapped or vibrated before each reading is taken.

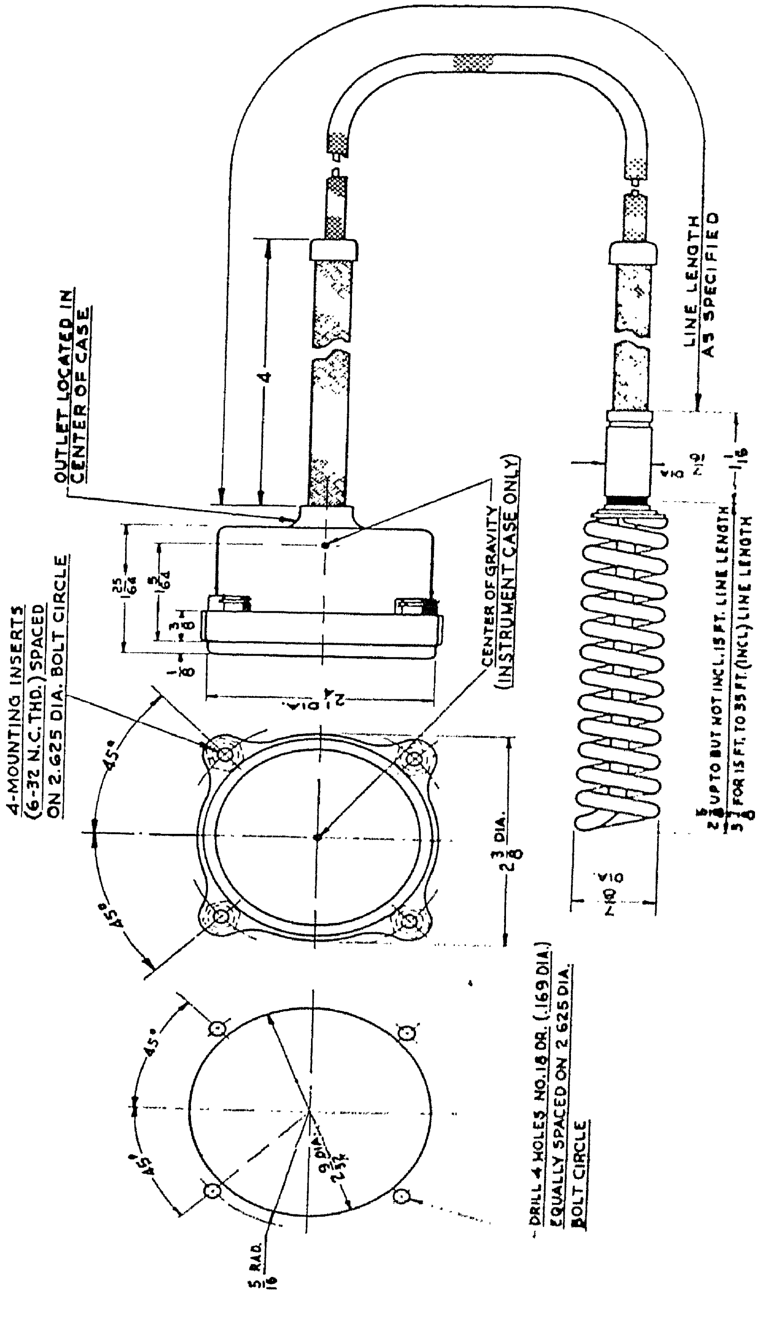
The following listed calibration tolerances represent the maximum, and much closer limits may be maintained with a little care.

Bulb Temperature C.	Indicated Temperature C. Allowable Error
−40	+ or −2
−30	2
−20	2
−10	2
− 2	0
0	0
2	0
10	2
20	2
30	2
40	2
50	2

In the event that recalibration is necessary the following data will be helpful.

Recalibration

Loosen set screws so they do not touch the Bourdon tube, subject bulb to −40° C. and set pointer. At this point, the


OUTLET LOCATED IN CENTER OF CASE
CENTER OF GRAVITY (INSTRUMENT CASE ONLY)
4-MOUNTING INSERTS (6-32 N.C. THD.) SPACED ON 2.625 DIA. BOLT CIRCLE
LINE LENGTH AS SPECIFIED
2 5/8 UP TO BUT NOT INCL. 15 FT. LINE LENGTH
3 1/8 FOR 15 FT. TO 35 FT. (INCL.) LINE LENGTH
DRILL 4 HOLES NO. 18 DR. (.169 DIA.) EQUALLY SPACED ON 2.625 DIA. BOLT CIRCLE
4
2 1/4 DIA.
2 3/8 DIA.
45°
5/16 RAD.

movement hairspring should have approximately one-half to three-quarters of a turn initial tension. Calibrate at several points between −40° C. and +10° C. by adjusting the slotted sector slide. Set the first retard screw to just touch the Bourdon tube at +10° C.; the first retard screw will carry the calibration to +20° C. Set the second retard screw tc just touch the tube at +20° C. This will carry the calibration to +30° C. Set the third retard screw to just touch the tube at +30° C.; this will carry the calibration to +40° C. Set the fourth retard screw to just touch the tube at +40° C.; this will carry the calibration to +50° C. The fifth retard screw is an over-range stop; set it to touch the tube at +50° C.; this will protect for a temperature of +60° C. Set the low temperature stop against the sector when the bulb is subjected to, and the pointer reads −40° C.

It will be found in actual practice that the number of retard screws required is usually not as great as mentioned in the foregoing. For example, a single retard screw may carry the calibration satisfactorily over a range of 20° instead of the 10° as outlined above. However, the above outline serves as a basis for all calibrations and should be followed to determine the individual characteristics of the instrument.

Installation

To mount the instrument, cut a hole in the instrument board for the case, and drill four screw holes as shown in Figure 7. Place the instrument in the board from the rear and secure firmly with #6-32 screws inserted from the front.

The thermometer bulb should be firmly attached to wing or strut of aircraft outside of the engine slipstream. Secure the capillary tubing to the aircraft at intervals throughout its length to prevent whipping or chafing. No bends should be less than 1½″ radius. Coil any excess tubing neatly and fasten to convenient part of the aircraft. Do not cut capillary tubing. Thermometer is filled with a volatile liquid and any loss of this liquid will render the thermometer inoperative.

CHAPTER 3

CARBURETOR AIR THERMOMETER

The carburetor air thermometer indicates the temperature of the carburetor intake air or the vapor temperature after carburetion. This indication allows the operator to maintain the temperature as low as possible for maximum engine efficiency, and high enough to prevent icing of the carburetor, the throttle control, or damage by ice to the supercharger vanes.

Figure 8 shows one type of carburetor air thermometer and Figure 9 demonstrates its internal mechanism.

Operation

The unit is comprised of a bulb, capillary tube, and a Bourdon spring system partially filled with a volatile liquid. The design is such that the junction of the liquid and vapor phase always remains in the bulb. As the liquid in the bulb is warmed, its vapor is transmitted through the capillary tube and into the Bourdon spring tube of the gauge proper. With the increased pressure, the Bourdon tube tends to straighten out corresponding to the bulb temperature. But since the vapor pressure of the liquid is not directly proportional to the temperature, it is necessary to progressively retard the movement of the Bourdon tube. The retard screws, Figure 9, rest against the Bourdon tube and may be adjusted to various settings to facilitate calibration in the high ranges.

As shown, the end of the Bourdon tube is connected to the linkage system and the movements of the Bourdon tube are transmitted through the link and sector to the hand staff on which rests the pointer. The "low temperature stop" prevents excessive "straining" of the Bourdon tube and the "sector slide" is used for low range calibration. The inertia disc serves as a resting plate for the hairspring (not shown) which removes the backlash of the mechanism.

CARBURETOR AIR THERMOMETER

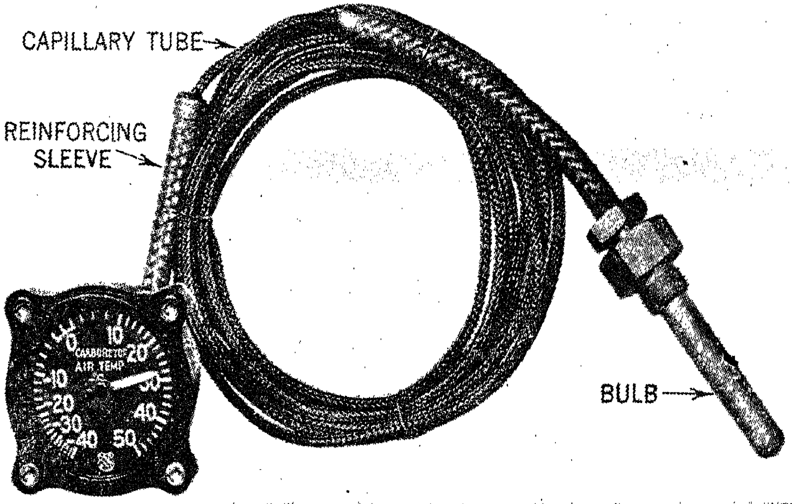


Figure 8. Ashcroft Carburetor Air Thermometer Type 6645

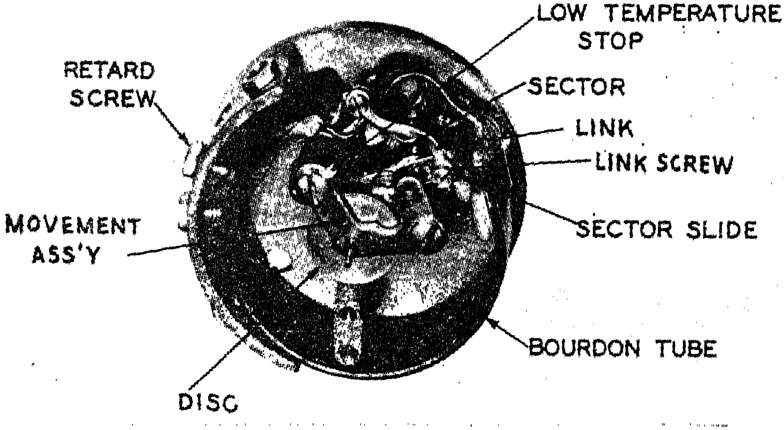


Figure 9. Mechanism of Ashcroft Carburetor Air Thermometer

Possible Causes of Failure or Inaccuracy

LEAK IN THERMOMETER SYSTEM. Renders thermometer inoperative; pointer will read approximately −40° C. at room temperature. *Note:* The large majority of failures due to leaking thermometer systems are caused by these factors:

(a) Chafing of the capillary tubing on parts of the airplane structure so that it wears through and the tubing is broken.

(b) Chafing of the tubing within its own reinforcing sleeves at the instrument or bulb. These sleeves are not designed to absorb vibration from the tube to the instrument but are used to insure the proper radius of turn of the tube into the bulb or instrument.

Failures as listed under (a) may be eliminated by proper clamping of the capillary tubing to the aircraft structure and failures as listed under (b) may be eliminated by clamping the capillary tubing just adjacent to the reinforcing sleeves at the bulb and at the instrument to the same structural member to which the bulb or instrument is attached. This eliminates the possibility of vibration of the capillary tubing within its reinforcing sleeves. If it is impossible to install the tubing as mentioned in the foregoing, the capillary tubing should be securely taped at its entrance into the reinforcing sleeve if the tubing is clamped to a member having a different vibrational characteristic than the member to which the instrument or gauge is attached.

CAPILLARY TUBING PLUGGED. Thermometer either inoperative or very sluggish.

EXCESSIVE FRICTION. If thermometer is not dead, rap instrument sharply and note if pointer assumes correct reading. If so, there is excessive friction or lost motion resulting from corrosion or wear.

LOOSE PARTS. If thermometer responds to changes in bulb temperature and does not appear to have excessive friction as outlined, an incorrect indication may be caused by loose parts.

Calibration

It is necessary to have a "cold" and "hot" bath, the former for temperatures from room temperature to −40° C. and the latter for temperatures from room temperature to 50° C.

The "cold" bath may be Prestone with a refrigeration unit used in conjunction, and the "hot" bath, water heated by a heating unit, the same as used for engine thermometers.

Loosen the set screws so they do not touch the Bourdon tube, subject the bulb to −40° C. and set the pointer. At this point, the movement of the hairspring should have approximately one-half to three-quarters of a turn initial tension. Calibrate at several points between −40° C. and +10° C. by adjusting the slotted sector slide. Set the first retard screw to just touch the Bourdon tube at +10° C.; the first retard screw will carry the calibration to +20° C. Set the second retard screw to just touch the tube at +20° C. This will carry the calibration to +30° C. Set the third retard screw to just touch the tube at +30° C.; this will carry the calibration to +40° C. Set the fourth retard screw to just touch the tube at +40° C.; this will carry the calibration to +50° C. The fifth retard screw is an over-range stop; set it to touch the tube at +50° C.; this will protect for a temperature of +60° C. Set the low temperature stop against the sector when the bulb is subjected to, and the pointer reads −40° C.

The following are the calibration tolerances:

Bulb Temperature C.	Indicated Temperature C. Allowable Error
−40	+ or −2
−30	2
−20	2
−10	2
− 2	0
0	0
2	0
10	2
20	2
30	2
40	2
50	2

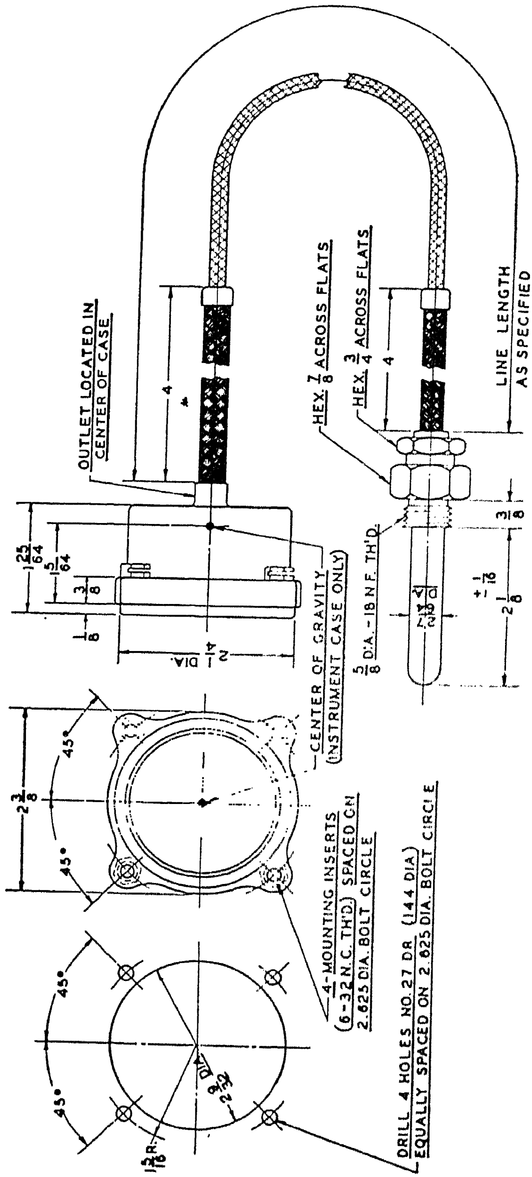


Figure 10. Installation Dimensions of Carburetor Air Thermometer

Installation

To mount the instrument, cut a hole as shown at the left. The instrument is mounted from the rear of the panel and held in place by four #6-32 screws inserted from the front.

Two different methods are used for connecting the bulbs of these thermometers. In one method, the bulb is located in the air intake connection. In the other, the bulb is located in the vapor passage between the carburetor and the manifold. Either method is satisfactory so far as the operation of the thermometer is concerned.

The capillary tube should be secured at intervals throughout its length to rigid members of the airplane, to prevent "whipping" or "chafing." No bends should be less than 1½" radius. Any excess tubings should be coiled neatly and fastened to a convenient part of the airplane.

CHAPTER 4

ENGINE THERMOMETER

The purpose of the engine thermometer is to indicate to the pilot the temperature of the oil in, oil out, or the cooling liquid of the engine. It warns against the overheating of the engine or its becoming too cold during a glide. It indicates when the oil is sufficiently warm for a safe take-off and assists in operating the engine at a temperature of maximum efficiency.

Operation

The instrument is a "vapor pressure" type and hence a pressure measuring instrument. It comprises a bulb, capillary (Figure 11) and Bourdon spring system (Figure 12) which is partially filled with a volatile liquid (sulphur dioxide) such that the junction of the liquid and vapor phase always remains in the bulb. The bulb is located in contact with the oil or cooling liquid of the engine and, as it is heated, the vapor pressure reacts and is transmitted through the capillary tubing to the Bourdon spring in the instrument. The greater the pressure the more the Bourdon tube will tend to straighten out. Since the linkage system is attached to the end of the Bourdon tube, it responds to the movement and transmits the deflection to the hand on the dial.

Since the vapor pressure of a liquid is not directly proportional to temperature, approximate uniformity of dial graduations is obtained by progressively "retarding" the deflection of the Bourdon spring by retard stops placed about the circumference of the spring, Figure 12.

Possible Causes of Failure or Inaccuracy

LEAK IN THERMOMETER SYSTEM. Renders thermometer inoperative; pointer will read approximately 0° C. at room

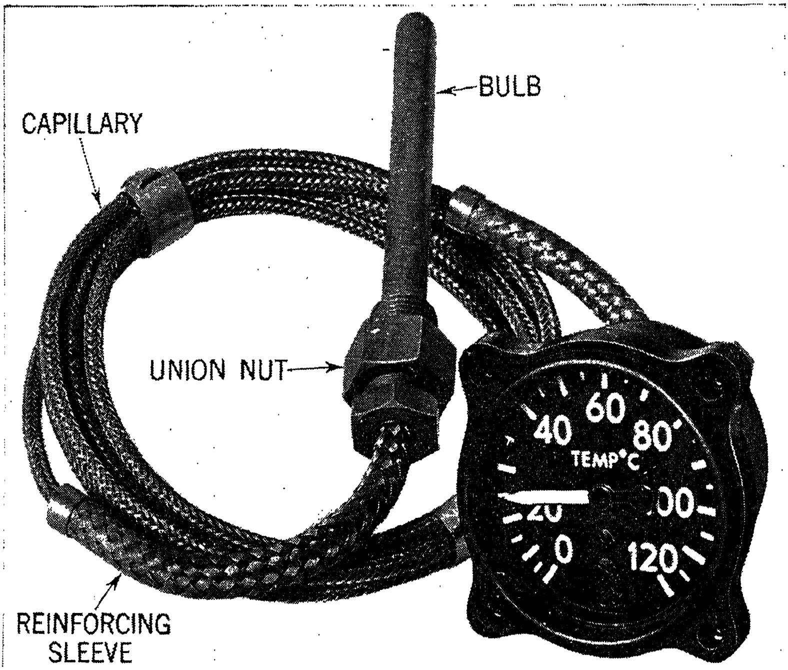


Figure 11. Ashcroft Engine Thermometer Types 6642, 6643, 6646

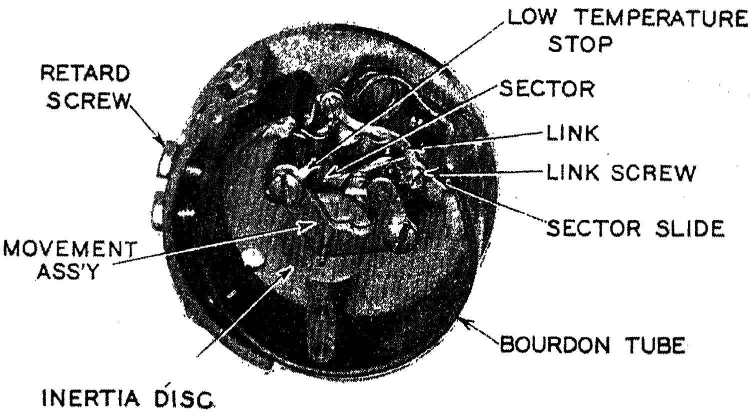


Figure 12. Engine Thermometer Mechanism

temperature. Replace with new thermometer system. *Note:* The large majority of failures due to leaking thermometer systems are caused by the following factors:

(a) Chafing of the capillary tubing on parts of the airplane structure so it wears through and tubing is broken.

(b) Chafing of the tubing within its own reinforcing sleeves at the instrument or bulb. These sleeves are not designed to absorb vibration from the tube to the instrument but are used to insure the proper radius of turn of the tube into the bulb or instrument.

Failures as listed under (a) may be eliminated by proper clamping of the capillary tubing to the aircraft structure and failures as listed under (b) may be eliminated by clamping the capillary tubing just adjacent to the reinforcing sleeves at the bulb and at the instrument to the same structural member to which the bulb or instrument is attached. This eliminates the possibility of vibration of the capillary tubing within its reinforcing sleeves. If it is impossible to install the tubing as mentioned in the foregoing, the capillary tubing should be securely taped at its entrance into the reinforcing sleeve if the tubing is clamped to a member having a different vibrational characteristic than the member to which the instrument or gauge is attached.

Capillary Tubing Plugged. Thermometer either inoperative or very sluggish. Replace with new system.

Excessive Friction. If thermometer is not dead, rap instrument sharply and note if pointer assumes correct reading. If so, there is excessive friction or lost motion resulting from corrosion or wear. Examine link bearings and movement carefully. Replace if necessary.

Loose Parts. If thermometer responds to changes in bulb temperature and does not appear to have excessive friction as outlined above, an incorrect indication may be caused by loose parts. Examine "retard" screws, adjustable slide or movement sector, links, pivot screws, etc.

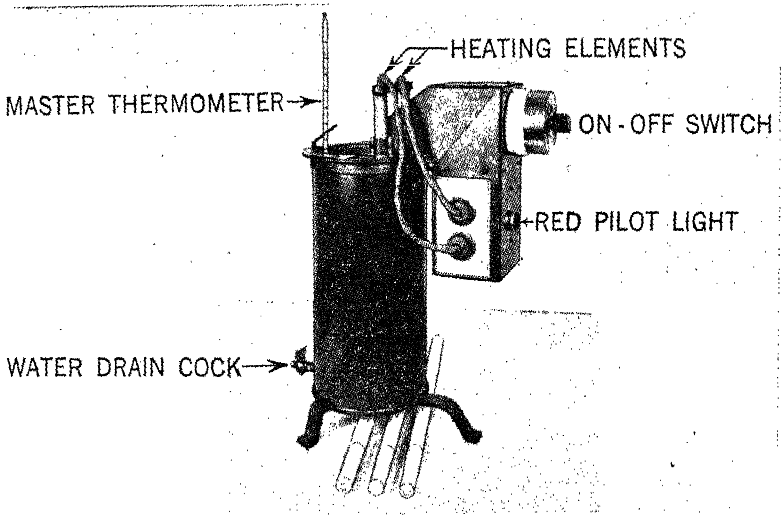


Figure 13. Pioneer Thermometer Testing Apparatus
(Pioneer Instrument Division of Bendix Aviation Corp.)

Test Apparatus

The tester is operated with a standard plug-in connection to a 110-volt AC circuit. The water container measures 6″ diameter and 12″ deep and is made of heavy gauge brass, reinforced at the bottom and top. The container is rigidly supported by three legs, providing desired stability; and is equipped with two 500-watt, 100-volt immersion heaters of standard commercial type, easily replaceable, with separate plug-in terminals, enabling them to be switched on individually or together.

A water agitator is incorporated on the container, and is operated by a 1/30 hp., 1750 r.p.m. motor, actuating, through a set of bevel gears of a suitable ratio, a vertical shaft carrying an impeller. Gearing and motor are well guarded and are of such characteristics as to maintain the water at a uniform temperature throughout the container.

The operation of the agitator is quiet and free from vibrations; and the motor and gears are protected from water splashes. The container is provided with drain cock, spring support for master glass thermometer, holding rack for six

temperature elements (bulbs) of distant reading type temperature gauges.

The apparatus is equipped with a red pilot light, showing that the electric system is in operation, although the failure of this light bulb does not interrupt the electric system. It includes also a four step electric switch for controlling the agitator motor and heaters, and four glass thermometers, used as a calibration standard. These thermometers are accurate within ½° C., range −10° to 100° C. The glass stems are about 7 mm. in diameter and have an overall length of about 12″.

Directions for Tests

For temperatures which are below room temperature, use method and equipment listed under Free Air Thermometer, page 12. For temperatures above room temperature, proceed as follows: Fill the water container to cover bulbs of the temperature gauges under test, place master glass thermometer in spring support, and switch on both elements until water is sufficiently warmed for testing. One element can then be switched off, leaving one for gradual temperature increase. Compare the test instruments with master as the temperature rises. Switch on both elements for testing of high temperature indications.

The following are the calibration tolerances.

Bulb Temperature C.	Indicated Temperature C. Allowable Error
0	+ or − 4
10	3
20	3
30	3
40	2
50	2
60	2
70	2
80	2
90	3
100	3
110	3
120	3

If above tolerances are not met, instrument may be recalibrated.

Recalibration

Loosen set screws so they do not touch the Bourdon tube, subject bulb to 0° C. and set pointer. At this point, the movement hairspring should have approximately one-half to three-quarters of a turn initial tension. Calibrate at several points between 0° C. and 40° C. by adjusting the slotted sector slide. Set the first retard screw to just touch the Bourdon tube at 40° C.; the first retard screw will carry the calibration to 60° C. Set the second retard screw to just touch the tube at 60° C. This will carry the calibration to 80° C. Set the third retard screw to just touch the tube at 80° C.; this will carry the calibration to 100° C. Set the fourth retard screw to just touch the tube at 100° C.; this will carry the calibration to 120° C. The fifth retard screw is an over-range stop; set it to touch the tube at 120° C.; this will protect for a temperature of 135° C. Set the low temperature stop against the sector when the bulb is subjected to, and the pointer reads 0° C.

It will be found in actual practice that the number of retard screws required is usually not as great as mentioned in the foregoing. For example, a single retard screw may carry the calibration satisfactorily over a range of 40° instead of the 20° as outlined above. However, the above outline serves as a basis for all calibrations and should be followed to determine the individual characteristics of the instrument.

Installation

Caution—Do Not Cut or Break the Armored Capillary Tubing. The Bourdon spring, armored capillary, and bulb contain a volatile liquid, and loss of the liquid will make the system inoperative. The capillary is necessarily fragile; due care to avoid damage shall be taken in installation.

Uncoil the capillary and install thermometer bulb in well or socket provided in the motor, and screw up union nut tightly. All of bulb should be in direct flow of liquid, not in dead space, for correct indications.

The capillary should not be placed near heated parts of the engine. There shall be no bends less than 1½″ radius. The

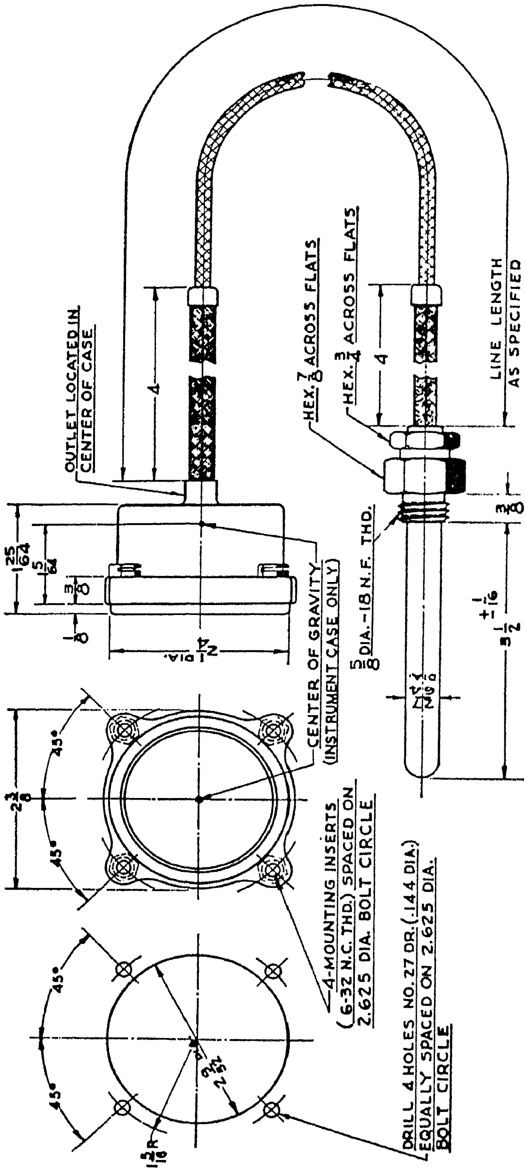


Figure 14. Installation Dimensions of Engine Thermometer

capillary shall be securely fastened throughout its length so that it cannot whip or chafe. *The capillary shall not be stretched and shall be secured free from strain.* Particular care must be taken to insure that the capillary is not under strain at or near the reinforcements located at each end of the capillary. Excess tubing shall be neatly coiled and fastened securely to a convenient part of the aircraft where it will be out of the way. Provision should be made for easy removal of the thermometer, capillary tubing and bulb, intact for replacement, without an undue amount of labor, and without mutilating any part of the aircraft.

CHAPTER 5

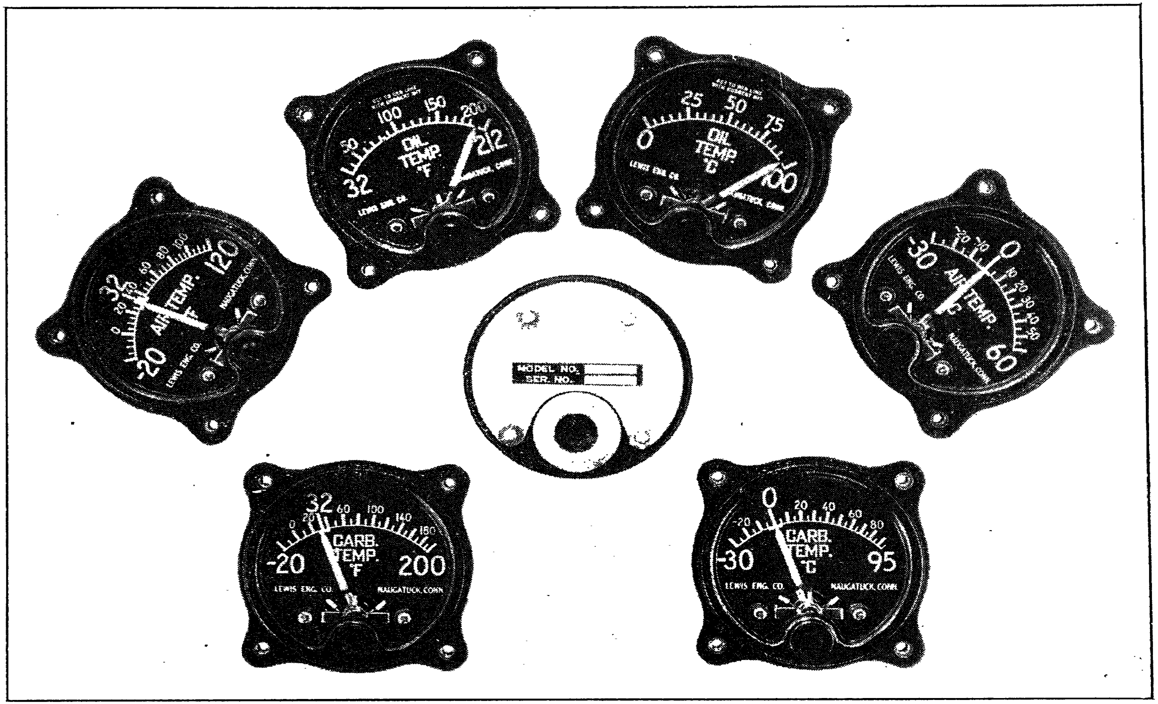
RESISTANCE THERMOMETER INDICATORS

(Carburetor Air, Outside Air and Oil Temperatures)

The purpose of these indicators is to register and indicate *electrically* the temperatures of the carburetor air, outside air, and oil temperatures. The pilot should familiarize himself with the minimum and maximum indications permissible for the best performance of his airplane.

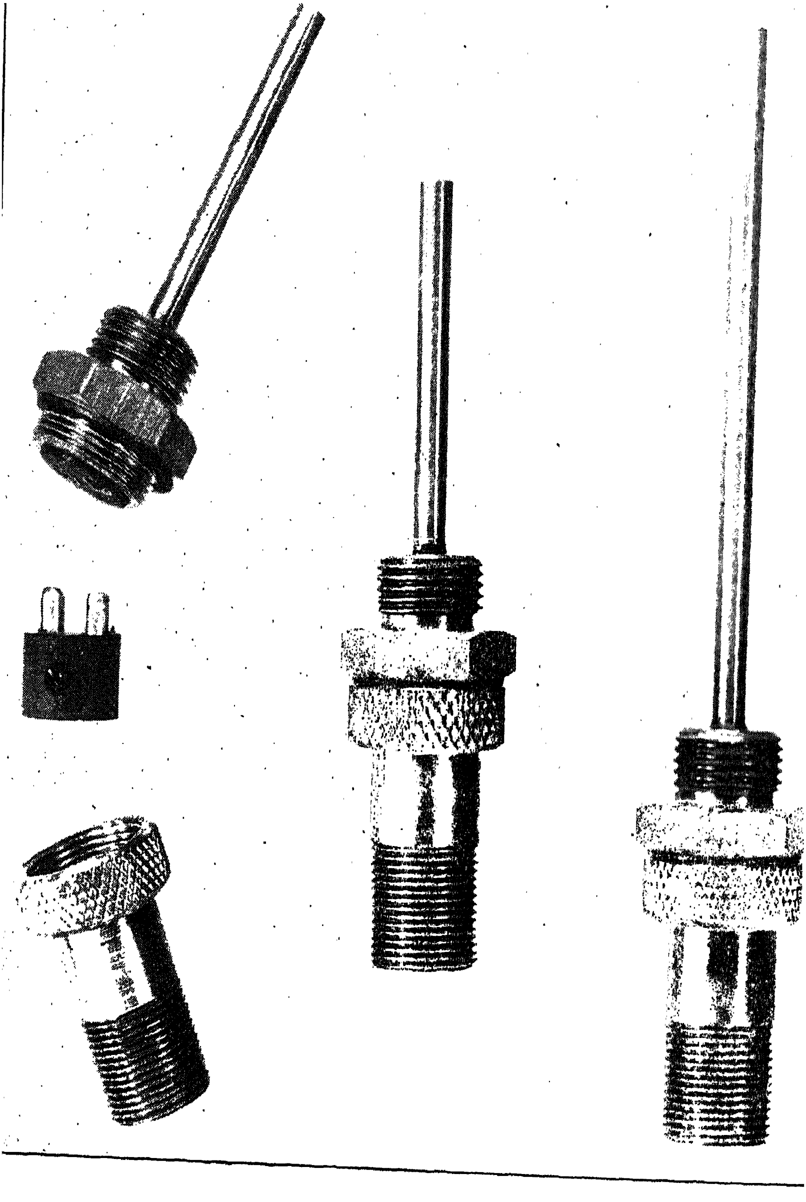
Resistance thermometer installations consist of three main parts: the indicating instrument as shown in Figures 15, 16, and 17, the temperature sensitive element (bulb) as shown in Figures 19 and 20, and the connecting lead wires between the indicating instrument and the bulb. The indicator consists of a sensitive D'Arsonval type mechanism having a permanent magnet and a moving coil. On the moving coil is mounted a large radium-treated pointer. This D'Arsonval mechanism is housed in a bakelite case. Over this bakelite case is a soft iron shield for the purpose of minimizing the effect of the indicator's permanent magnet on a magnetic compass.

The temperature sensitive elements (bulbs) consist of a winding of specially selected pure nickel wire wound on an anode-treated aluminum tube. The two ends of the nickel winding are soldered to a twin-plug connector. The protection tube is made of monel metal, the end of the tube being press-fitted, rounded over, and silver soldered into a hexagon head. The twin-conductor plug is made of ceramic having molded into it two silver-plated brass split pins. They also include an adaptor which is designed to cover the connecting plug, and which is threaded to receive the nut on the end of the static shield over the conductors. A gasket is provided between the adapter and the hexagon head in order to seal against moisture. These bulbs are interchangeable with each other.



Resistance Thermometer Indicators

Figure 15 *(lower left)*. Lewis Carburetor Temperature Indicator. Figure 16 *(upper left)*. Lewis Air Temperature Indicator. Figure 17 *(top row, second from left)*. Lewis Oil Temperature Indicator. Figure 18 *(center)*. Rear View. *(Lewis Engineering Co.)*



When these bulbs are used, the construction of the back of the instrument is as follows: Three connections are brought out in a bakelite block for the purpose of connecting the indicator to the sensitive bulb and to the source of current supply. Over the terminals there is a static shield arranged to take standard shielding material for shielding the conductors in order to eliminate any interference with the radio.

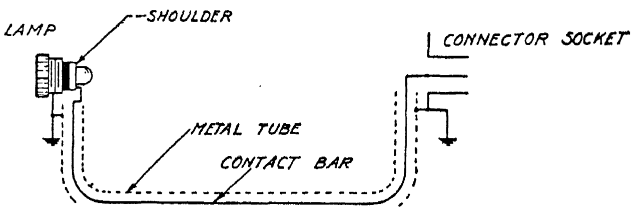


Figure 21. Indicator with Individual Lighting System

Some indicators are equipped with an individual lighting system (see Figure 21) which consists of a small lamp, removable from the front of the indicator, and a connecting socket extending to the rear of the indicator arranged to receive a connecting plug which is to be connected to the current supply through a series resistor.

Detailed Description

There are three spools wound with manganin wire mounted on the back-plate of each instrument. These spools are connected so as to form three arms of a Wheatstone Bridge. The fourth arm of the bridge is the sensitive element (bulb).

The instrument mechanism is connected across two opposite corners of the bridge, and the source of current supply is connected across the two remaining corners of the bridge; the instrument mechanism serving as a galvanometer.

Referring to Figure 22, the three arms are designated as (A), (B), and (C), and are wound to have a definite resistance, depending on the type of bulb used and the mechanical zero point on the instrument.

All sensitive bulb elements are wound to have a resistance of 100 ohms when subjected to a temperature of 0° C. They change resistance with changes in temperature. If the mechanical zero point on the instrument is at 0° C., the three arms (A), (B), and (C), will be wound to have a resistance of exactly 100 ohms.

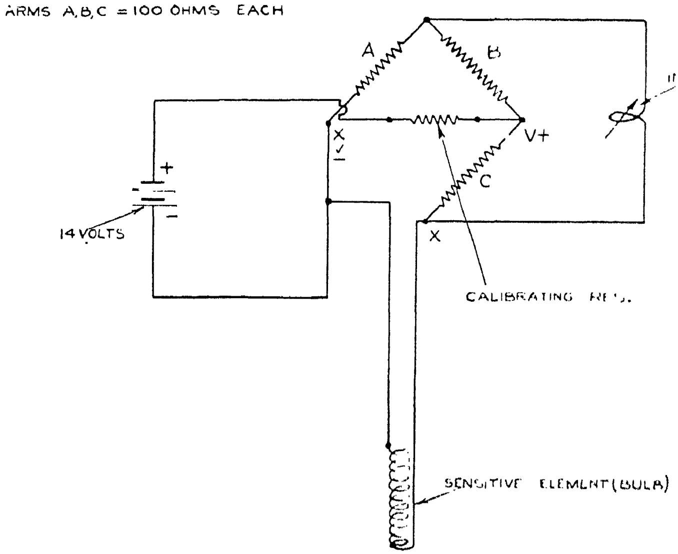


Figure 22. Wiring Diagram, Instrument

The system is calibrated by inserting into the battery circuit resistance. The temperature scale is laid out to conform to the curvature of the temperature coefficient of the bulb and also the characteristics of the instrument mechanism and the predetermined actuating voltage.

Operation

The electrical thermometer requires a source of current supply. In some cases this is a 12-volt battery, in which case the calibrating voltage used is 14 volts. In other cases the instruments are actuated by a 24-volt plane's battery, in which case the calibrating voltage used is 28 volts.

When the sensitive element is exposed to a temperature of 0° C., its resistance will be 100 ohms. If the mechanical zero is at 0° C., the arms (A), (B), and (C), will have a value of 100 ohms each. The indicating instrument will have no current flowing through its moving coil when the bridge circuit is in a balanced condition, and for the values given above, this will be when the bulb is at 0° C.

When the sensitive element is exposed to a temperature higher than the temperature of the normal zero of the instrument, its resistance will increase, thereby unbalancing the bridge

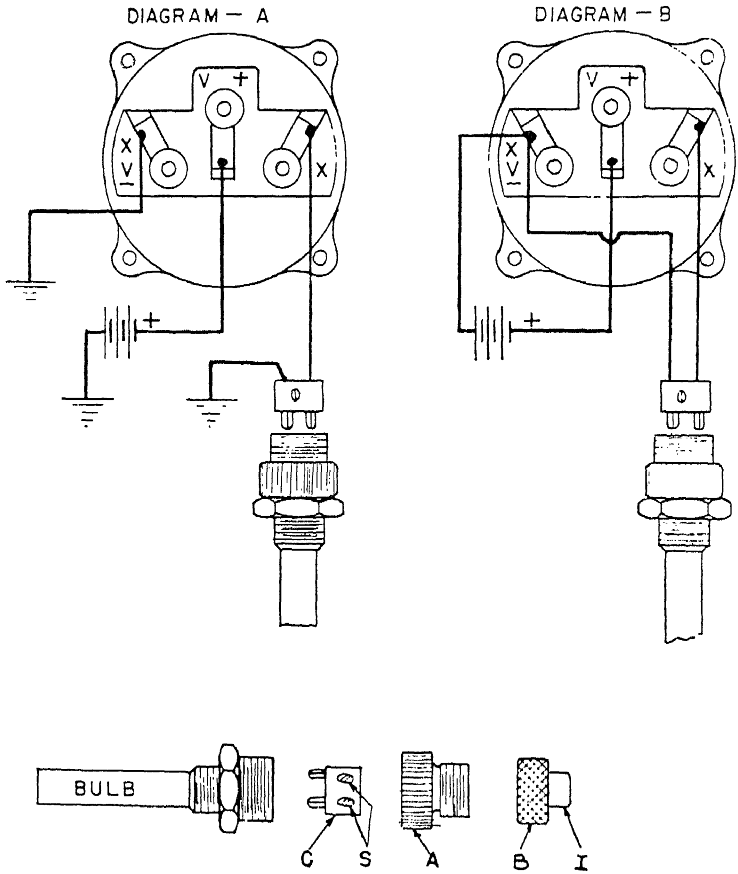


Figure 23. Wiring Diagrams, Installation

in such a direction as to cause the indicating pointer to deflect toward the right, indicating the increase in temperature. Likewise, when the temperature sensitive bulb is exposed to a temperature lower than that of the normal zero of the instrument, the bridge will be unbalanced in a direction so as to cause the pointer to deflect toward the left part of the scale, thereby indicating the fall in temperature.

Installation

The instrument is mounted on the panel and held in place by four #6/32 screws. The resistance bulb is located at its temperature source in a threaded hole, the thread being ⅝–18 N.F.–3.

Connect the instrument and resistance element by means of copper conductors (not smaller than #16B and S Gauge).

When installing either type 52B or 67B bulb, remove the insulation for about ¼″ on the ends of the wires and scrape the wires clean. Remove the adapter (A), Figure 23, exposing the bayonet plug (C). Pull out plug (C), slip wires through (A) and by means of screws (S) as indicated, secure the wires to the plug. Replace plug (C) into the bulb and replace adapter (A).

Figure 23 indicates two wiring diagrams, A and B, for installations using 52B, or 67B bulbs. Diagram A shows a grounded system, and diagram B shows a system insulated from the ground. As to operation, both methods of wiring function identically.

Inspection and Maintenance

At the end of every fifty hours of flight, interrupt the current supply to the instrument, check and adjust the instrument's normal zero.

No servicing of the bulb is required. Unless the bulb is damaged by excessive heat due to backfiring of the engine, it should function indefinitely.

The bulb will withstand for short periods of time temperatures of 300° C. Before condemning or reporting either

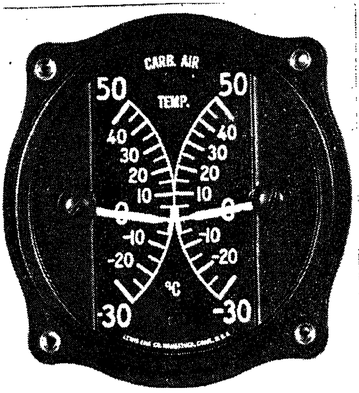


Figure 24. Lewis Dual Carburetor Air Temperature Indicator

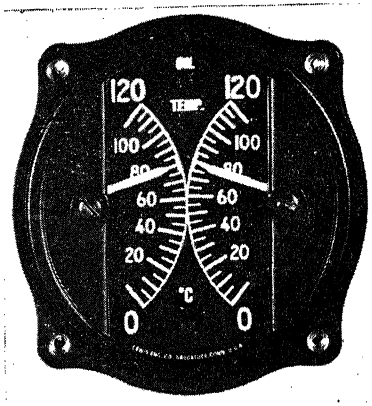


Figure 25. Lewis Dual Oil Temperature Indicator

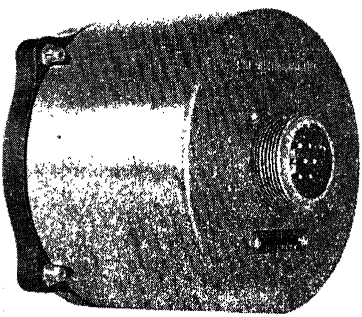


Figure 26. Rear View

the indicator or bulb as being unserviceable check all connections for a loose or shorted connection especially at the bulb end.

The jewels of the indicating instrument will under no condition be oiled. No service lubrication is required.

When an individual lighting system is used and it ceases to function, replace the 3V. lamp installed in upper right-hand lug of the instrument. If, after replacing the lamp, the lighting system does not function, the electrical circuit beyond the disconnect plug on the rear of the instrument should be checked.

Equipment Troubles and Remedies

Check to insure that all connections are clean and tight and free from exposure to excess oil or water and that the lead insulation is not frayed or broken. Occasionally trouble may develop in an installation due to wear, or severe vibration. To assist in locating its cause a table is given below showing "Trouble," "Possible Cause," and the recommended "Remedy."

TROUBLE CHART

TROUBLE	POSSIBLE CAUSE	REMEDIES
(a) No reading with panel switch "ON."	Panel switch defective.	Replace.
	Poor connection at switch terminals.	Repair.
	Break in battery lead.	Repair.
	Break in ground lead.	Repair.
	Battery dead	Charge.
	Open or short circuit in indicator.	Replace and return indicator to service station.
(b) Reading off scale at low temperature end.	Short circuit in leads to resistance bulb.	Repair.
	Ground in lead from resistance bulb to "R" post of indicator.	Repair.
	Short circuit in resistance bulb.	Replace and return to service station.
	Open or short circuit in indicator.	Replace and return indicator to service station.
(c) Reading off scale at high temperature end.	Break in leads to resistance bulb.	Repair.
	Open circuit in resistance bulb.	Replace.
	Open short circuit in indicator.	Replace and return indicator to service station.
(d) Low or high reading either permanent or intermittent.	Battery low.	Charge.
	Poor connections in leads to battery.	Repair.
	Poor connection in leads to panel switch.	Repair.
	Poor connection in panel switch.	Repair.
	Poor connection in leads from indicator to resistance bulb.	Repair.
	Zero corrector off adjustment.	Open battery circuit and reset indicator by zero adjusting screw to balance point.

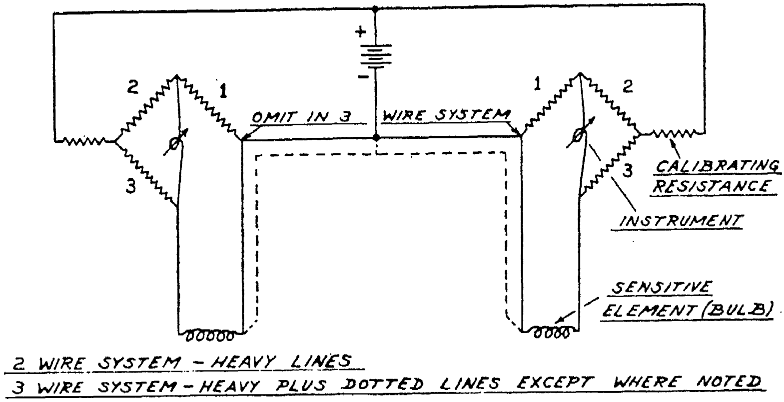


Figure 27. Dual Indicator Wiring Diagram

The dual carburetor air, outside air, and oil temperature indicators are constructed similar to the single indicators but giving dual indications.

The operation, inspection and maintenance, and equipment troubles and remedies which apply to the single indicators likewise apply to the dual indicators.

The electrical wiring of the instrument and system however differs and is shown in Figures 27 and 28.

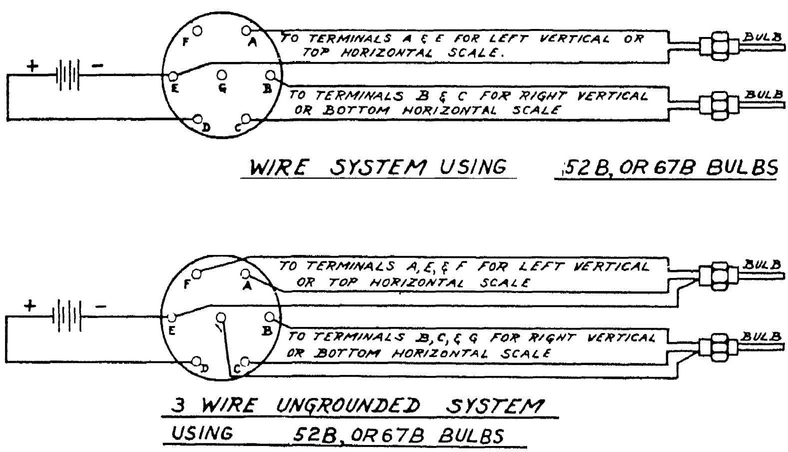


Figure 28. System Wiring

CHAPTER 6

ENGINE GAUGE UNIT

The engine gauge unit combines the fuel pressure, oil pressure, and oil thermometer into one instrument. The fuel pressure indicates the pressure in the fuel feed system, the oil pressure indicates the pressure in the lubricating system, and the oil thermometer indicates the temperature of the lubricating oil in the engine.

This type of an arrangement permits the reading of the three indications at a single glance, as well as saving space on the instrument panel.

Operation

The thermometer is a "vapor pressure" type, and hence essentially a pressure measuring instrument. It comprises a bulb, capillary and Bourdon spring system partially filled with a volatile liquid such that the junction of liquid and vapor phase always remains in the bulb. The vapor pressure corresponding to the bulb temperature is transmitted through the capillary tubing to the Bourdon spring in the instrument. Since the vapor pressure of a liquid is not directly proportional to temperature, approximate uniformity of dial graduations is obtained by progressively "retarding" the deflection of the Bourdon spring by retard stops placed about the circumference of the spring. The indicating mechanism in the case consists of the Bourdon spring and a precision pinion and sector movement which transmits deflection of Bourdon spring to the thermometer pointer.

The oil and fuel pressure gauges are of conventional Bourdon spring design. Each is connected by ¼″ metallic tubing to its pressure source. As the oil and fuel pressure increases in the tubing and Bourdon springs, the Bourdon springs tend to

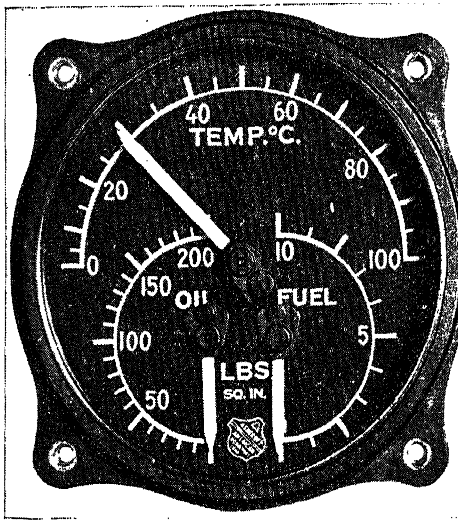


Figure 29. Ashcroft Engine Gauge Unit Type 6642

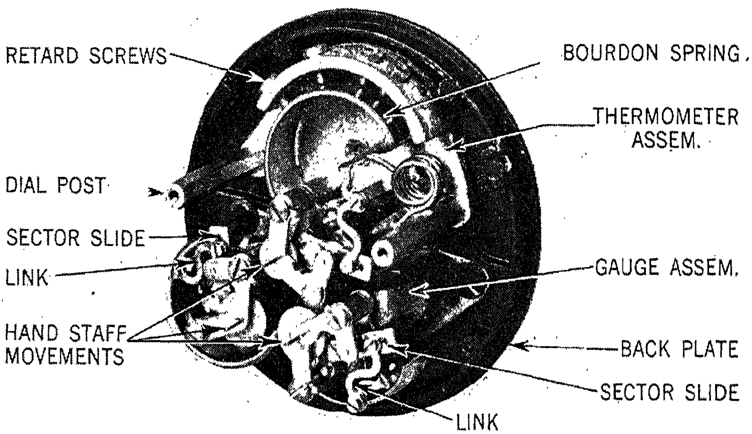


Figure 30. Mechanism of the Engine Gauge Unit

straighten out, the attached linkage is moved, and the movements transmitted to the pointers on the dials, indicating oil and fuel pressure in pounds per square inch.

Possible Causes of Failure or Inaccuracy

Oil Thermometer. (a) Leak in thermometer system. Renders thermometer inoperative; pointer will read approximately 0° C. at room temperature.

(b) Capillary tubing plugged. Thermometer either inoperative or very sluggish.

(c) Excessive friction. If thermometer is not "dead," rap instrument sharply and note if pointer assumes correct reading. If so, there is excessive friction or lost motion resulting from corrosion or wear. Examine link bearings and movement carefully.

(d) Loose parts. If thermometer responds to changes in bulb temperature and does not appear to have excessive friction as outlined above, an incorrect indication may be caused by loose parts. Examine "retard" screws, adjustable slide on movement section, link screws, etc.

Oil and Fuel Pressure Gauges. (a) Failure of the Bourdon spring or a leak. Renders the gauge inoperative. If in the Bourdon spring, it should be replaced. If the tubing is cracked or split causing a leak, the tubing should be replaced.

(b) "Set" in the Bourdon spring. This is usually caused by excessive pressure, in which case the pointer will not return to zero. It will be necessary to shift the pointer and recalibrate the instrument.

(c) Loose parts. Will cause an incorrect indication by the pointer.

Testing Procedure

In testing the oil thermometer, the same type of equipment used for testing Free Air Thermometers may be used. To test the fuel and oil pressure gauges the equipment listed under oil pressure gauge may be used.

Calibration

Thermometer. Place the bulb in melting ice, loosen the retard screws so they do not touch the Bourdon tube, and set the pointer to zero. At this point, the movement hairspring should have approximately one-half to three-quarters of a turn initial tension. Calibrate at several points between zero and 40° C. by adjusting the length of the slotted sector slide. After correct calibration is obtained from zero to 40° C., next set first retard screw to just touch the Bourdon tube at 40° C. First retard screw will carry the calibration from 40° C. to 60° C. Next, set second retard screw to just touch Bourdon tube at 60° C.; this will carry the calibration from 60° C. to 80° C. Set third retard screw to just touch Bourdon tube at 80° C.; this will carry calibration from 80° C. to 100° C. Fourth retard screw is an over-range stop; set it to touch the Bourdon tube at 100° C. Set the low temperature stop against the sector when the bulb is subjected to, and the pointer reads 0° C.

It will be found in actual practice that the number of retard screws required is usually not as great as mentioned in the foregoing. For example, a single retard screw may carry the calibration satisfactorily over a range of 40° instead of the 20° as outlined above. However, the above outline serves as a basis for all calibrations and should be followed to determine the individual characteristics of the instrument.

Pressure Gauges. Calibration of the pressure gauges is by means of: (a) adjusting the link with respect to the slotted sector slide to give pointer correct range for dial, and (b) varying length of S-shaped link to give desired scale characteristics at intermediate dial calibrations.

Adjustments respond as follows:

1. For (a) moving the link in increases the pointer travel for a given applied pressure and vice versa.
2. For (b) lengthening the link progressively decreases the pointer movement as the applied pressure increases, and vice versa.

After calibration the instruments should be given the following calibration check. The instruments should be tested in an upright vertical position and should be lightly tapped before each reading is taken.

Thermometer.

Bulb Temperature C.	Indicated Temperature C. Allowable Error
0	+ or 4
10	3
20	3
30	3
40	2
50	2
60	2
70	2
80	2
90	3
100	3

Pressure Gauges.

Actual Pressure	Indicated Pressure Fuel		Oil
	0–25#	0–10#	0–200#
0			
2	.4	.2	
4	.6	.3	
6	.6	.3	
8	.6	.3	
10	.6	.4	
15	.6	.4	5.0
20	.8		
25	.8		
40	.8		5.0
80			5.0
120			5.0
160			5.0
200			5.0

Installation

To mount the instrument, cut a hole in the panel for the case and drill four screw holes as shown in Figure 31. In the center drawing are shown the oil and fuel connections. The ¼″

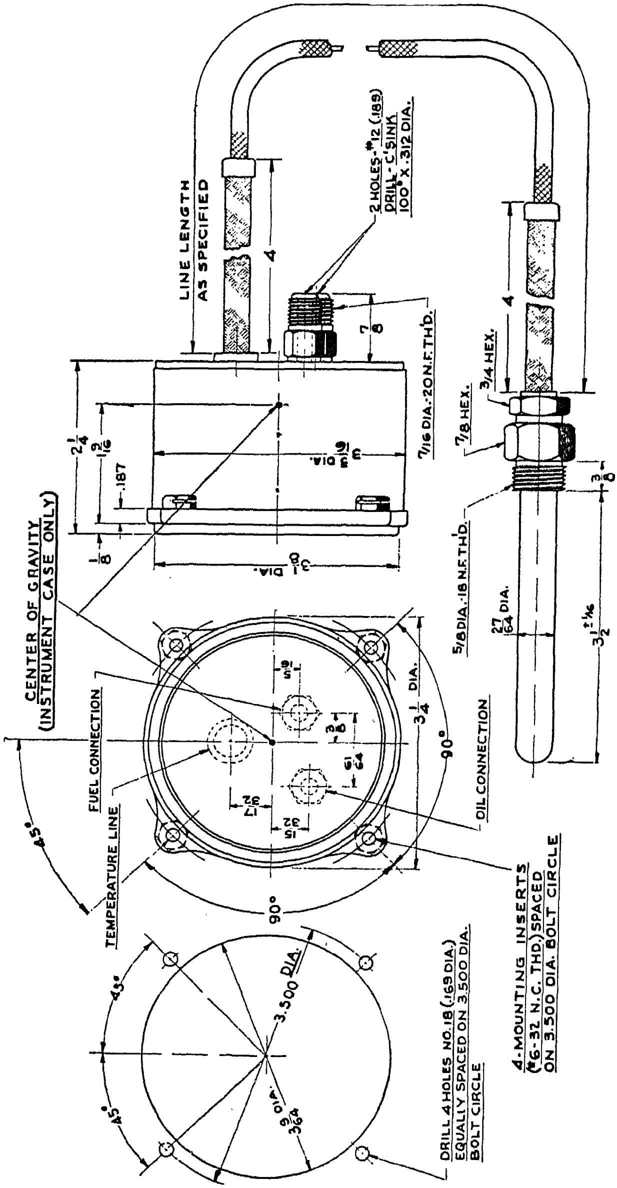


Figure 31. Installation Dimensions of Engine Gauge Unit

tubing for these instruments is routed from the rear of the case to their respective sources of pressure. The tubing is to be clamped at intervals to rigid members of the airplane to prevent "swaying."

The capillary tube of the oil thermometer is necessarily fragile, and although it is protected by armored tubing, care must be taken in installation to prevent damage. Since the capillary tube contains a volatile liquid, any break or rupture to the tube will render the thermometer inoperative. The tube should be clamped to rigid members of the airplane and protected by rubber grommets at the point where it passes through the fire-wall. It should not be placed near heated parts of the engine. There should be no bends less than 1½" radius. *The capillary shall not be stretched and shall be secured free from strain.* Particular care shall be taken to insure that the capillary is not under strain at or near the reinforcements located at each end of the capillary. Excess tubing shall be neatly coiled and fastened securely to a convenient part of the aircraft where it will be out of the way. Provision shall be made for easy removal of the thermometer, capillary tubing and bulb, intact for replacement, without an undue amount of labor, and without mutilating any part of the aircraft.

CHAPTER 7

SUCTION GAUGE

Most gyroscopic instruments used on modern aircraft operate by suction created by the vacuum pump. Each of the instruments, such as the turn and bank, artificial horizon, directional gyro and the automatic pilot are designed to function on a definite pressure and whenever this pressure is inaccurate the readings of the instruments are inaccurate.

The purpose of the suction gauge is to indicate to the pilot the true suction pressure of each instrument.

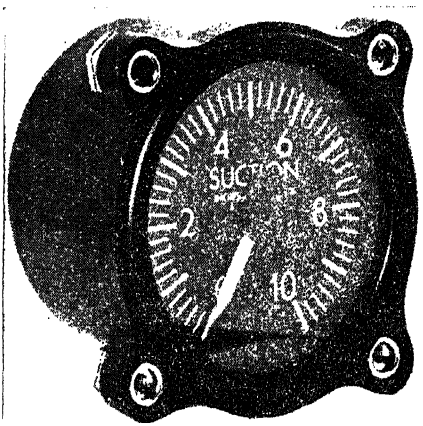


Figure 32. Ashcroft Suction Gauge Type 6702

If the instruments are to be used for take-off it is necessary for the pilot to be sure that they have been operating under the proper suction for the specified time interval. The turn and bank indicator operates accurately under 2″ of mercury vacuum after five minutes during which time the gyro rotor will attain the correct speed of rotation. The artificial horizon, directional gyro, and automatic pilot function properly at 3½″ of mercury after five minutes.

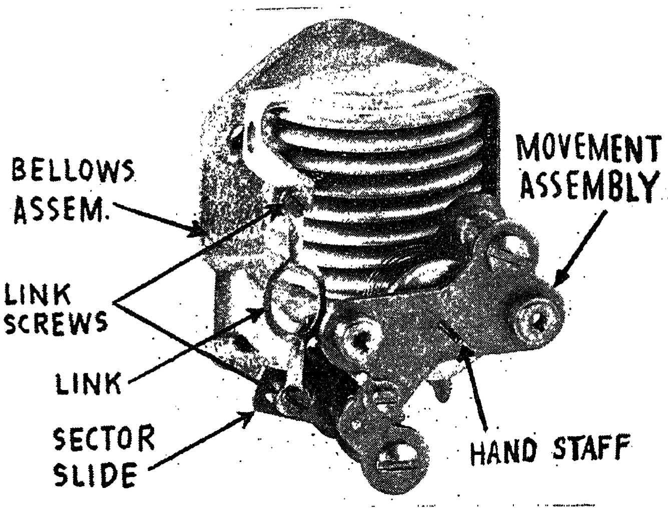


Figure 33. Suction Gauge Mechanism

In flight the same suction pressures apply. The suction gauge also may serve as a check, to a certain measure, on the vacuum pump. In the event that the vacuum pump fails completely, the reading of the gauge will drop to zero reading. It is not uncommon for more than one suction gauge to be used on the instrument panel. Therefore, if all gauge readings return to zero it is definite proof that the vacuum pump has failed. The pilot then may, by the use of a selector switch, switch to another vacuum pump on another engine provided a dual- or four-motored airplane is being flown. In the case of a single-motored airplane depending solely on the vacuum pump for suction, the pilot should then disregard the readings of all gyroscopic instruments, even though readings may still be obtained for several minutes. The readings will be faulty since the gyro rotors in the instruments will be slowing down.

Operation

The vacuum gauge line is connected to the inside of the bellows and its position is governed by the vacuum pressure in relation to the surrounding atmospheric pressure. To elucidate,

whenever the pressure on the inside of the bellows equals the pressure on the outside of the bellows, the hand on the dial will indicate zero. As a suction is created in the vacuum line, the bellows will move inward. By means of the linkage system the hand-staff will be rotated and the hand will move over the face of the dial indicating inches of mercury suction. The sector slide is for adjustments and a hairspring (not shown) takes up the backlash of the movement.

Possible Causes of Failure or Inaccuracy

(a) A leak in bellows renders gauge inoperative or causes low indication. Replace bellows assembly.

(b) Excessive friction resulting from dirt or wear. Examine movement gear teeth, movement bearings and link bearings carefully. Clean or replace. NO LUBRICATION OF ANY KIND IS REQUIRED.

(c) A zero reading may indicate the failure of the suction pump, plugged line, or broken line.

Calibration

Calibration adjustments are made by:

(a) Positioning of link in slotted sector slide to provide pointer movement corresponding to "range" of dial. Moving link in increases pointer movement.

(b) Varying form of loop in link to give curve characteristics which conform to intermediate scale calibration divisions. Lengthening the link makes the pointer travel progressively less for increasing applied vacuum.

The gauge should be connected to a source of vacuum. A mercury column or master suction gauge should be teed into the line for reference. As the suction is increased, readings are taken from the gauge under test and compared with the master reference.

Calibration tolerances are given in the following table. After calibration, the hairspring should have one-half to three-

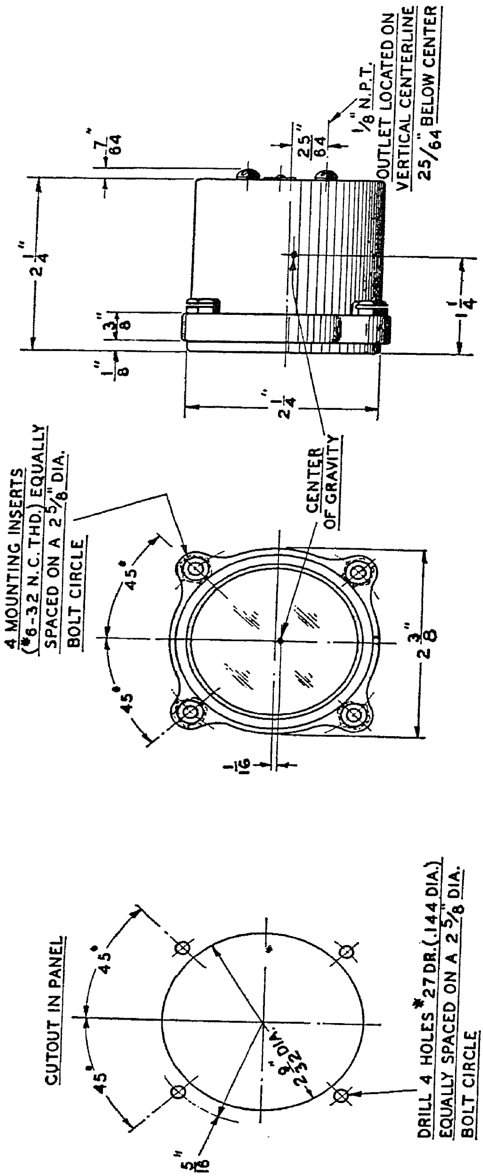


Figure 34. Installation Dimensions of Suction Gauge

quarters of a turn of initial tension at 0″ Hg, if it winds up with increasing vacuum, or one-half to three-quarters of a turn initial tension at 10″ Hg, if it unwinds with increasing vacuum. If it is necessary to adjust this tension, the calibration must be rechecked.

Actual Vacuum Inches of Mercury	Tolerance
0	.1 inch
2	.2
4	.2
6	.2
8	.2
10	.2

Installation

All outline and panel cutout dimensions are shown in Figure 34. The instrument is mounted in a 2 9/32″ diameter hole in the panel and held in place by four #6-32 screws. It should be connected with a ¼″ line to the vacuum supply, as near as possible to the instrument whose reading is desired. In some installations a vacuum regulator is installed in the line between the vacuum pump and the gyroscopic instruments. If the suction gauge line is inserted in this line between the vacuum regulator and the instruments, allowance must be made for indicated reading and the actual vacuum at the instruments. This difference is due to pressure drop, and must be determined for the particular installation.

CHAPTER 8

FUEL PRESSURE GAUGE

Most modern aircraft are equipped with a fuel pump located between the fuel tank and the carburetor. Its purpose is to draw the fuel from the tank and force it under pressure to the carburetor to insure an adequate supply regardless of the flying attitude of the aircraft. Of paramount importance, then, is the fuel pressure gauge which indicates this pressure, which is usually between 3 and 4 lbs./sq. in.

The fuel pressure gauge of the vented type indicates fuel pressure above carburetor pressure.

Operation

The fuel pressure acting within the Bourdon tube causes the Bourdon tube to be deflected as shown by the arrow, Figure 36. The movement of the tube carries the link and sector slide upward and the geared sector meshing with the pinion movement (not shown) rotates the pointer staff to which is attached the pointer. The pointer moves across the dial indicating fuel pressure in pounds per square inch.

Possible Causes of Failure or Inaccuracy

(a) A leak or failure at the Bourdon tube renders the gauge inoperative and necessitates replacement of the Bourdon assembly

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listorted tube should be

bly.

(c) Excessive friction resulting from dirt or wear. Examine the movement gear teeth, movement bearings and link bearings

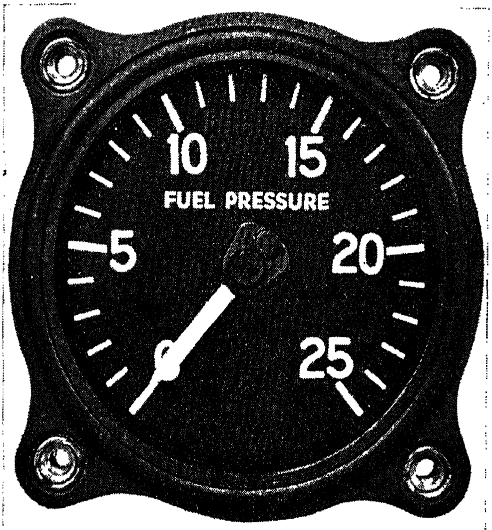


Figure 35. Ashcroft Fuel Pressure Gauge Type 6750

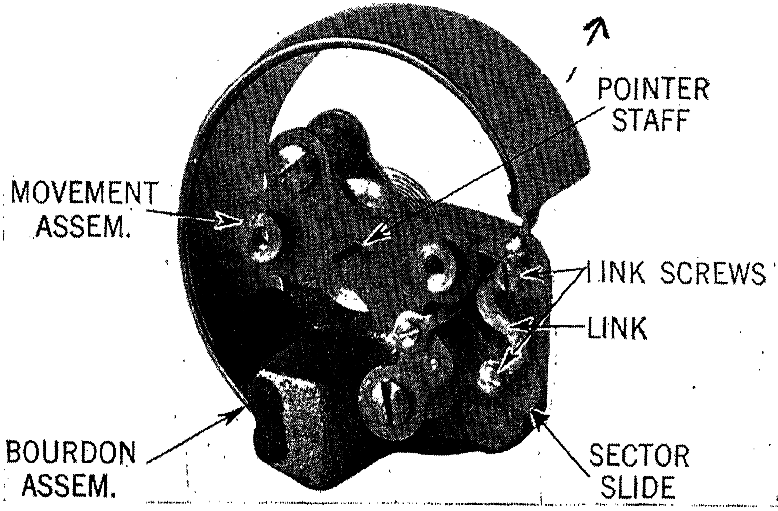


Figure 36. Mechanism of Ashcroft Fuel Pressure Gauge (Vented Type)

carefully. Clean or replace. NO LUBRICATION OF ANY KIND IS REQUIRED.

(d) A leaking case or vent line will cause low fuel pressure indication when manifold pressure is above surrounding atmospheric pressure. The indication will be high when manifold pressure is below surrounding atmospheric pressure. Repair the tubing or reseal the case.

Calibration

Calibration adjustments are made by:

(a) Positioning of the link in the slotted sector slide to provide pointer movement corresponding to "range" of the dial. Moving link in increases the pointer movement and vice versa.

(b) Varying length of S-shaped link to give curve characteristics which conform to intermediate scale calibration marks. Lengthening link makes the pointer movement progressively less for increasing applied pressures and vice versa.

Calibration tolerances are given in the table below. After calibration the hairspring should have ½ to ¾ turn of initial tension at 0 lbs./sq. in. If it is necessary to adjust this tension, the calibration must be rechecked.

Testing

After calibration the instrument should be checked on the conventional pressure type equipment. Tolerances shown below represent the maximum limits.

Pressure lbs./sq. in.	Tolerance lbs./sq. in.
0	+ or − 0.2
5	0.3
10	0.3
15	0.3
20	0.4
25	0.4

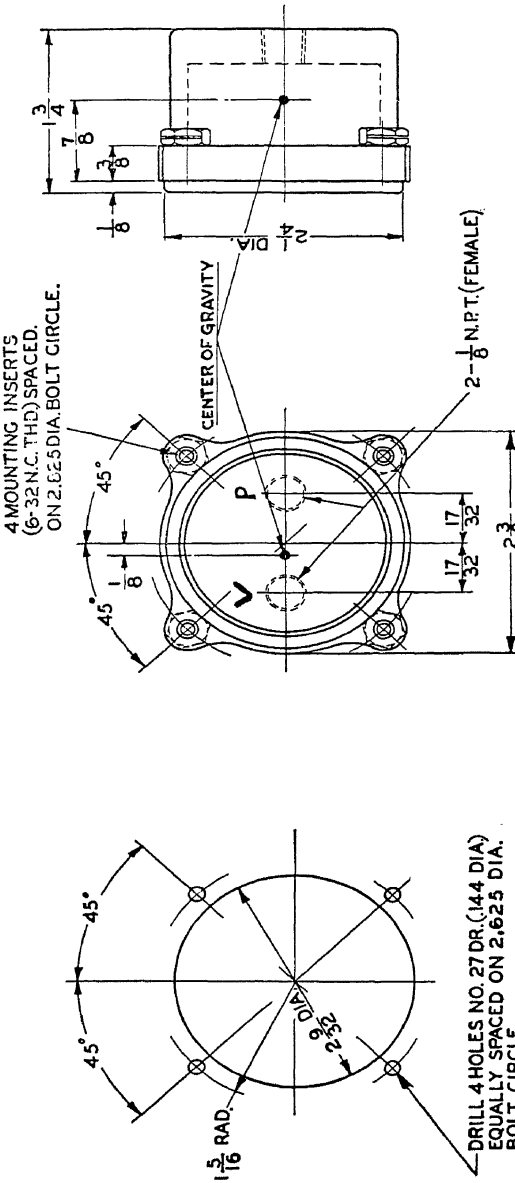


Figure 37. Installation Dimensions

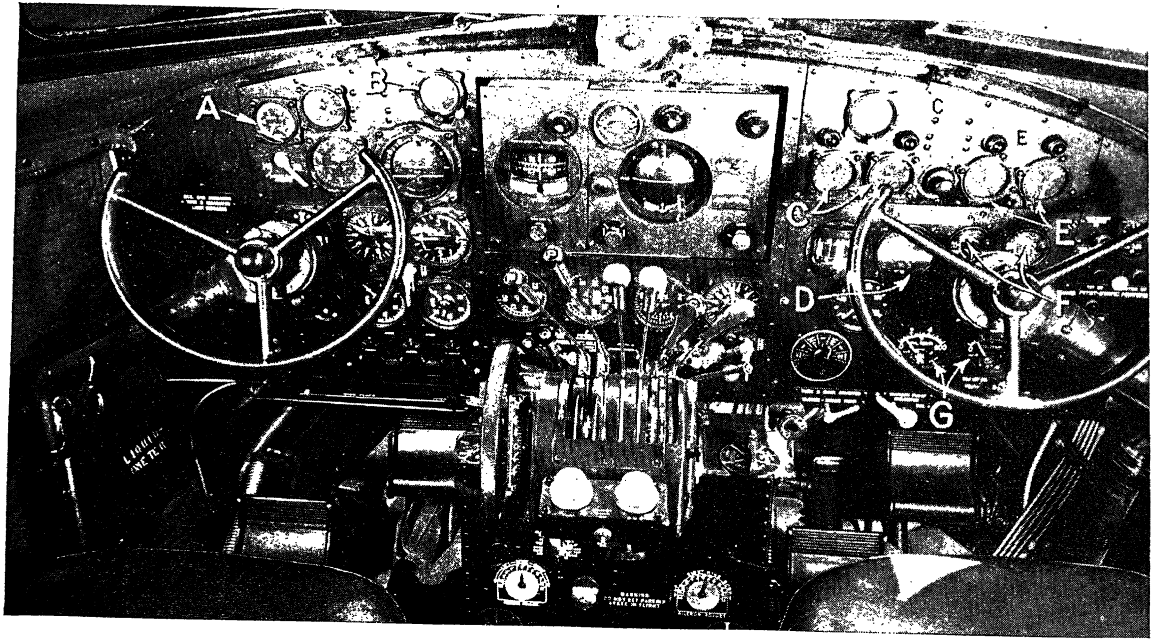


Figure 38. Douglas DC-3 Commercial Transport Panel
(Douglas Aircraft Co., Inc.)

A—Suction Gauge
B—Clock
C—Fuel Pressure Indicators
D—Air Temperature Indicator
E—Oil Pressure Indicators
F—Oil Temperature Indicators
G—Cylinder Temperature Indicators

The Douglas DC-3 Commercial Transport Panel presents an array of modern instruments. A well-planned installation layout makes it possible for the pilot and co-pilot to ascertain the indications of the various instruments instantly.

Installation

The panel cut-out is shown at the left. The instrument is mounted from the back of the panel and secured by four #6-32 screws. The ¼″ fuel line is connected to the pressure coupling (P). If the instrument is to be used as a differential fuel pressure gauge, remove the pipe plug from the outlet (V), add a coupling and connect to the manifold pressure line. (Figure 37.)

The lines should be securely clamped to rigid members of the airplane to prevent "swaying" or "chafing."

CHAPTER 9

ACCELEROMETER

In order to change the velocity of an airplane either in magnitude or direction, a definite force must be applied, which

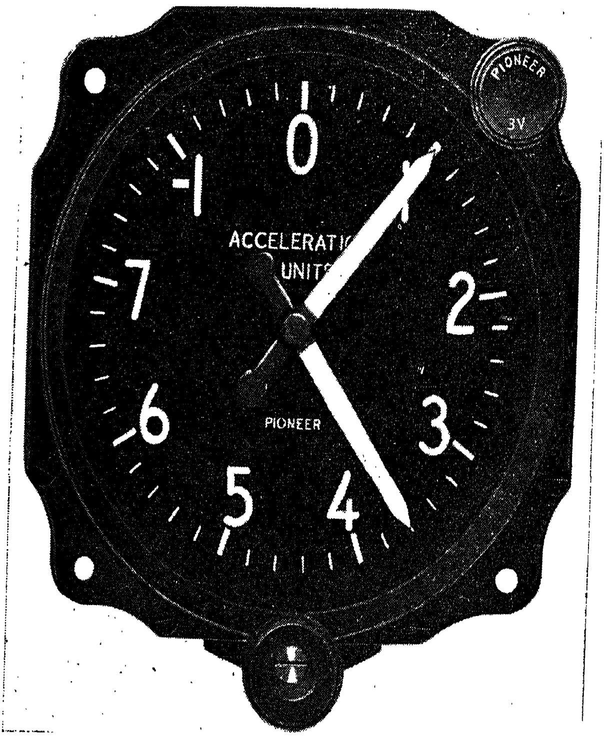


Figure 39. Pioneer Type 3401-1A
(Pioneer Instrument Division of Bendix Aviation Corp.)

force, according to an elementary law of physics, is directly proportional to that change in velocity. The term "acceleration" is the name physicists have applied to the process of

From the above, it is evident that a measure of the accelerations which the airplane encounters would give a definite indication of the forces applied to the airplane and its occupants and thus assist the pilot in limiting his maneuvers in accordance with the designed structural strength of the airplane and the comfort of its occupants. The accelerometer is particularly useful in assisting the pilot to maintain passenger comfort when flying in rough, bumpy air.

An acceleration of $1.2g$ is hardly noticeable by the occupants of the airplane but when the accelerations reach 1.5 or $1.6g$'s they become quite noticeable. The structure of the airplane landing gears can take up to $4.2g$'s or perhaps slightly more but usually the acceleration should not exceed 1.2 or $1.3g$'s. Correctly executed banks of 30° in a turn cause acceleration of about $1.2g$'s.

Dial and Hand Movement Description

The pointer moves clockwise 8/9 of a revolution for the range of $+8g$ units and 1/9 of a revolution in a counterclockwise direction for the range of $-1g$ unit. The dial is graduated into equal divisions of 0.2 of $1g$ unit throughout the range of the instrument. A second pointer is provided to record the maximum reading for any particular maneuver. This pointer may be reset by turning the knob at the bottom of the case.

Operation of Kollsman Type

The indicator consists of two weights (A) mounted at the ends of long lever arms (B). The gravitational force due to acceleration along the Z axis (the axis normal to both the lateral and longitudinal axes) on the weights is transmitted by lever action to the rocking shaft (C) and by means of a sector (not shown) the motion is transferred to the handstaff pinion. Restraining springs (D) restrict the movement of the weights in the direction of the Z axis, while two compensating sectors (E) meshed together preclude any error in indication due to acceleration along either of the remaining axes. A ratchet lever

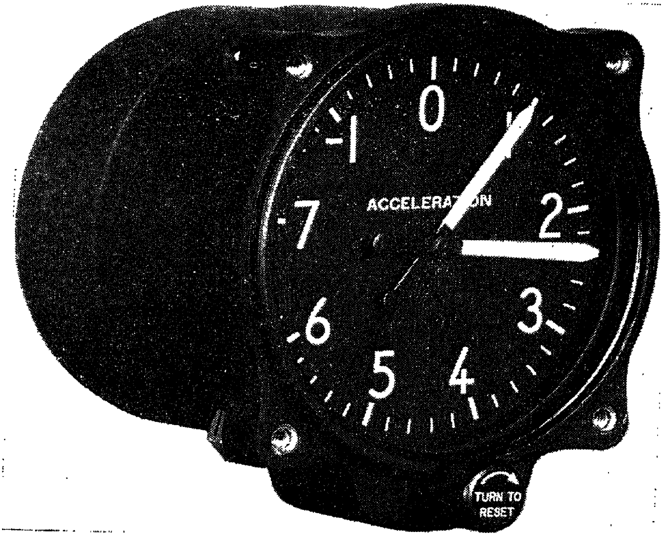


Figure 40. Kollsman Type 312

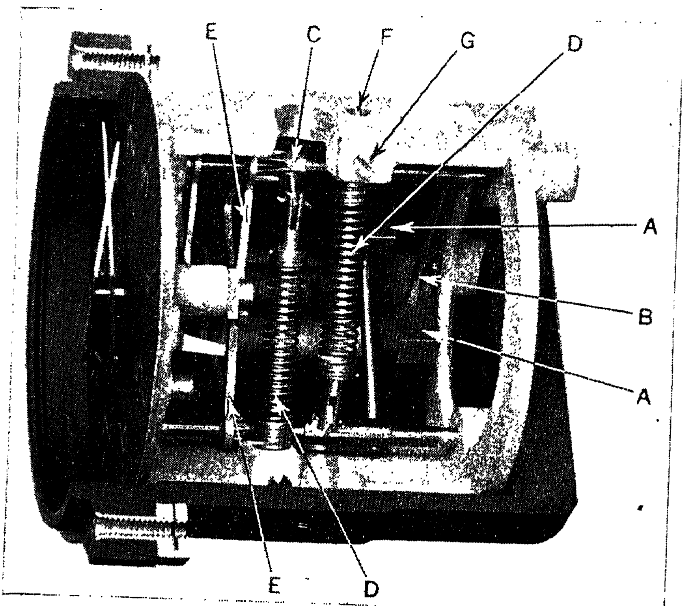


Figure 41. Cut-Away View Kollsman Accelerometer
(Kollsman Instrument Division of Square D Co.)

assembly (not shown) regulates the movement of the maximum pointer, whose position may be reset by turning the adjustment knob on the case. The range of the instrument is fixed by stop springs (not shown).

As the airplane is pulled out of a dive the centrifugal force is increased, causing the weights to move in the direction of the force. The movement of the weights is transmitted to the hand-staff by means of the sector. The auxiliary pointer follows the main pointer and remains at the maximum indication of the main pointer.

Installation

For maximum performance and life, it is recommended that this instrument be mounted on a panel suitably damped for vibration. The maximum amplitude (total movement) of vibration should not exceed 0.008″ at ordinary engine frequencies.

The accelerometer does not require any pressure connections and needs to be merely installed in the panel so the instrument dial is vertical and normal to the line of horizontal flight with the zero graduation at the top center of the dial.

Note: This paragraph applies to Pioneer ringlighted instruments only.

Electrical connections for the ringlight on the types 3401 are made in the following manner: After unscrewing the ferrule retaining nut, the ferrule should be swedged or soldered to the ¼″ conduit after first sliding the conduit retaining nut on the cable. The insulation should then be removed from the two wires for a length of approximately 3/16″. By twisting and tinning the two stripped wires, a better connection can be made to the female plug assembly. The female plug assembly should be removed from the plug housing and the two clamping screws loosened. After inserting the two tinned wires in the two receptacles of the female plug assembly and tightening them with the two screws provided, the plug assembly should be pushed back into the plug housing and the ferrule retaining nut screwed down tightly. The male ringlight plug assembly in the

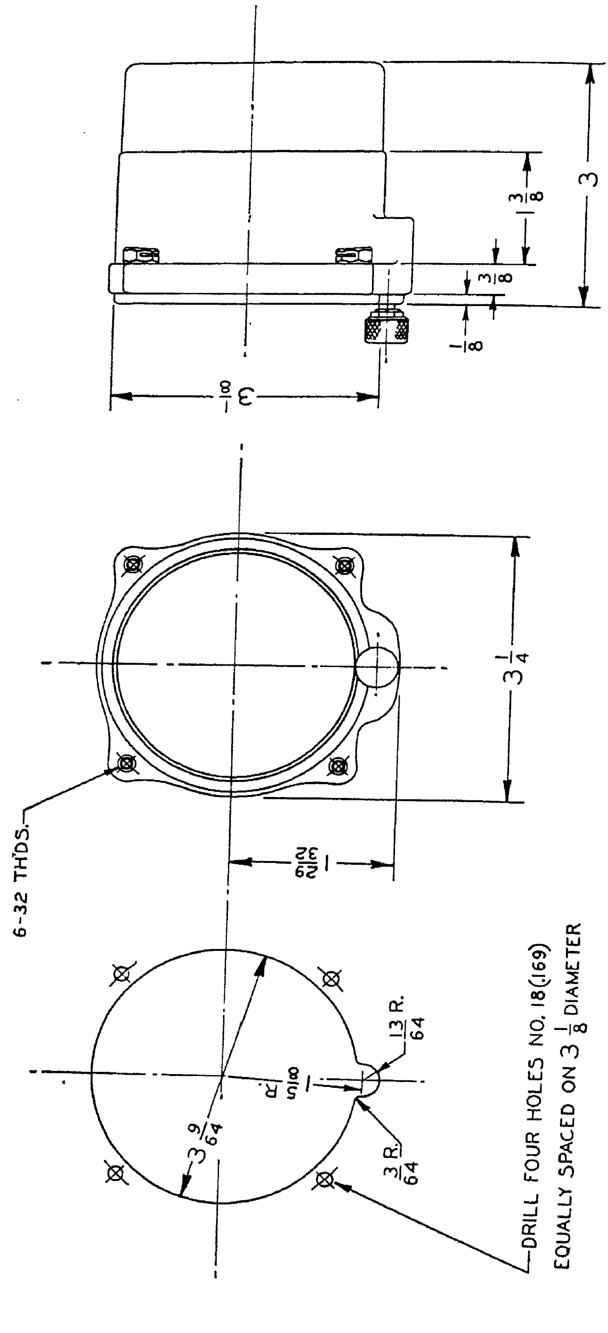


Figure 42. Installation Dimensions Kollsman Type 312
(Kollsman Instrument Division of Square D Co.)

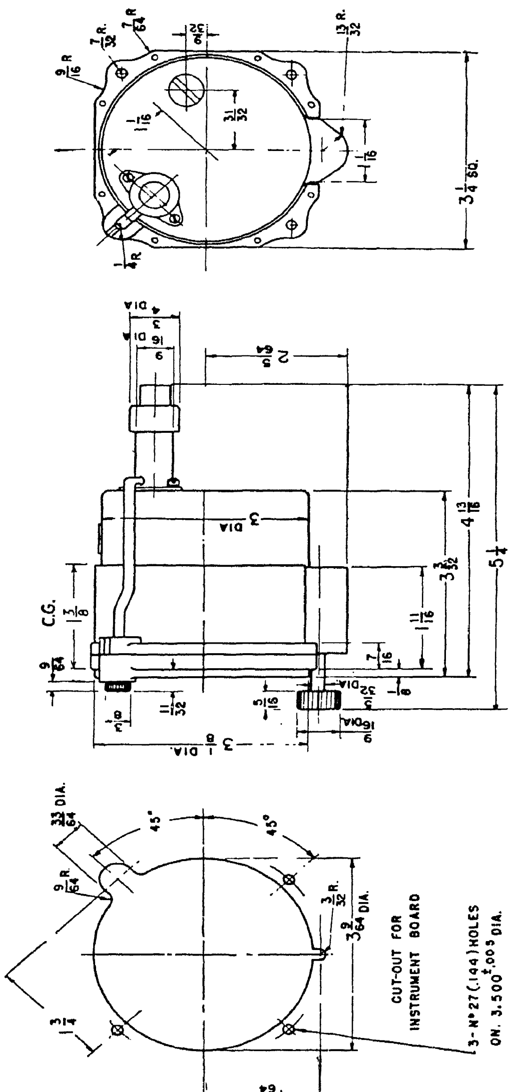


Figure 43. Installation Dimensions Pioneer Type 3401-1A
(Pioneer Instrument Division of Bendix Aviation Corp.)

bottom of the plug housing contains the resistor that limits the current to the 3-volt lamp to 0.2 amperes when the rated voltage is applied to the plug.

Maintenance

If it is desired to check the calibration of the accelerometer on the line, the instrument must be removed from the panel and the following procedure followed: With the instrument dial in the horizontal plane, the pointer should read "0", plus or minus $0.2g$, when the instrument is lightly tapped. The reset knob should be manipulated during this operation to be sure the maximum reading pointers are following correctly. When the instrument is held so the dial plane is vertical and the zero graduation at the bottom, it should indicate "$-1g$," plus or minus $0.2g$. The zero reset knob should be manipulated so the maximum reading hand will be free to indicate in the same position. With the dial of the instrument in the vertical plane and the zero graduation at the top of the dial, with light tapping, the pointer should indicate "$+1g$" within plus or minus $0.2g$. While handling the instrument in this manner, care should be exercised to be sure the instrument is not subjected to violent shocks which might cause damage to the mechanism.

CHAPTER 10

CYLINDER TEMPERATURE INDICATOR

In the operation of internal combustion engines for aircraft, it is essential to know the temperatures of such parts as the combustion head, cylinder base, and often other temperatures whose control is essential for safe performance and highest efficiency.

As there is an upper temperature limit beyond which it is not safe to operate, it follows that temperature measuring equipment is necessary, and it is important that it be kept in accurate condition at all times.

The thermocouple thermometer consists of three main parts to make up a complete temperature measuring system for aircraft, namely, the indicator as shown in Figure 44, and the thermocouple, and thermocouple leads as shown in Figure 46.

The thermocouples are made up of iron and constantan or copper and constantan of calibrated material, are insulated with asbestos, and covered with a cotton outer braid impregnated with a flame- and moisture-resistant lacquer. The thermocouple junction is made in a copper gasket ring for fitting over a spark plug of the engine. The other end of the thermocouple is equipped with suitable terminals for joining it to the thermocouple leads.

The thermocouple leads are made of the same material and construction as the thermocouples described in the previous paragraph. The leads are equipped at one end with suitable terminals to fit the thermocouples, and at the other end with suitable terminals to fit the positive and negative studs on the back of the indicator. The wire in the thermocouples and the lead wires may be identified by the color of asbestos insulation, black identifying iron, red signifying copper and yellow indicating constantan.

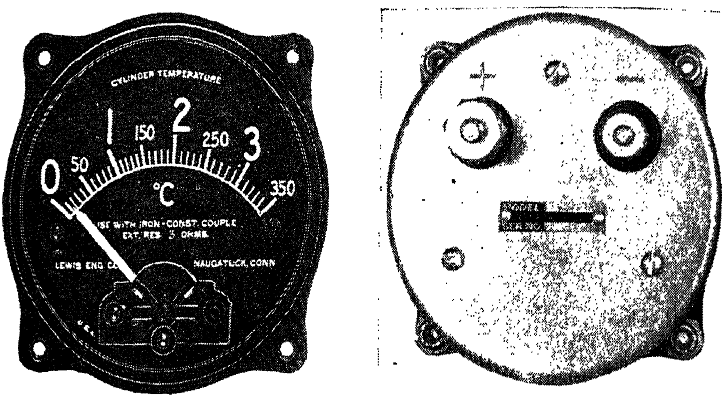


Figure 44. Lewis Single-Engine Cylinder Temperature Indicator
(Lewis Engineering Co.)

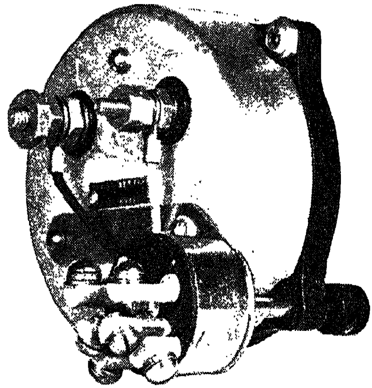


Figure 45. Lewis Single-Engine Cylinder Temperature Indicator with 9S Switch
(Lewis Engineering Co.)

Description

The indicator is a sensitive D'Arsonval type mechanism having a coil arranged to move in an annular air gap of a permanent magnet. The coil carries the pointer, and the control consists of two phosphor bronze springs which also serve to conduct the current into the coil. The thermocouple leads and the thermocouple are made of iron and constantan or copper and constantan, having a total circuit resistance of 2, 3, or 8 ohms. Constantan is an alloy of copper and nickel.

When two dissimilar wires are joined together to form a junction (generally called the hot junction), and the junction is heated, an electromotive force will appear at the other ends of the two wires (generally called the cold junction). The magnitude of the electromotive force depends upon the difference in temperature between the hot and the cold junction and upon the composition of the metals used.

As the electromotive force generated depends upon the difference in temperatures between the hot junction (the spark plug thermocouple washer) and the cold junction (the cold junction extends inside of the instrument case), it follows that in order to indicate the true temperature at the spark plug some means must be employed to correct the indicator for the varying temperature to which it is exposed remembering that the cold junction is located inside of the instrument. The instrument is corrected (compensated for cold junction temperature changes) by means of a bi-metallic spiral spring. The outer end of this compensating spring is attached to one of the control springs of the instrument which causes the instrument to be actuated not alone by the voltage of the thermocouple, but also by the temperature surrounding the instrument itself. In other words, when the thermocouple lead is disconnected from the instrument, the instrument will indicate the temperature of itself, that is, of the location where it is installed.

A negative temperature coefficient resistor is included in series with the moving coil of the instrument. The purpose of this resistor is to compensate for the positive temperature coefficient of the moving coil.

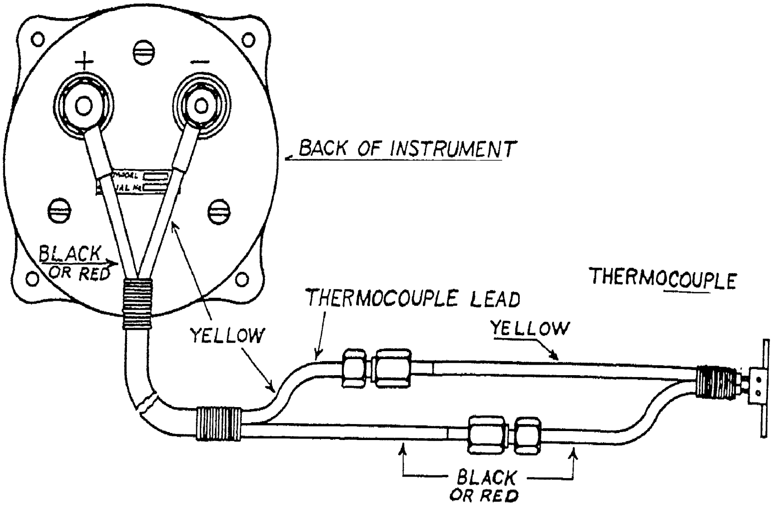
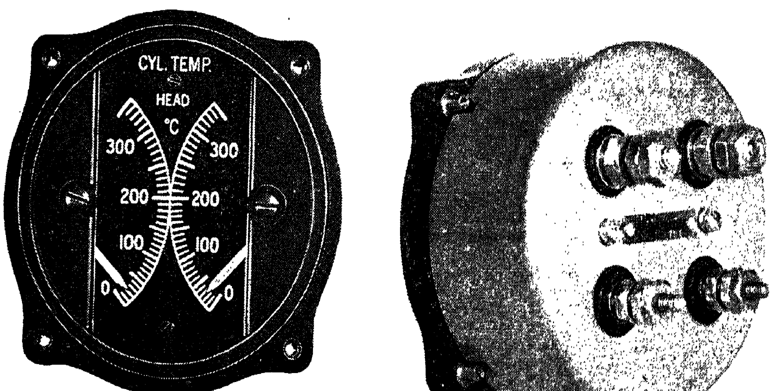


Figure 46. Single-Indicator Hookup



FRONT VIEW

REAR VIEW

Figure 47. Lewis Dual-Engine Cylinder Temperature Indicator
(Lewis Engineering Co.)

The thermocouples and thermocouple leads are so selected as to have a definite electromotive force per degree within an allowable tolerance.

Some indicators are arranged for individual lighting, having a small 3-volt lamp replaceable from the front of the instrument. The current supply is connected by means of a plug assembly arranged to plug into the socket on the rear of the instrument.

Selector Switch

Selector switches are varied in construction. They may indicate for two to any number of points. Figure 49 shows the terminals of a four-point switch with an "off" position and positive and negative connections. By rotating the knob (Figure 48) to the indicated numerals, temperatures at four different points may be obtained.

Operation

This instrument after installation in the cockpit, installation of thermocouples, and installation of thermocouple leads, is then a complete installation for indicating the true temperature at the point of thermocouple installation on the engine regardless of the temperature in the cockpit surrounding the indicator.

The operation of the system consists simply and entirely of reading the temperature by noting the position of the pointer on the graduated dial.

Testing

Connect the instrument to the thermocouple leads, and the thermocouple leads to the thermocouple. Then immerse the spark plug thermocouple into a bath of finely cracked ice and water. After stirring the ice bath for a minute or so, observe the reading of the indicator which should be 0° C. Care should be taken that very little water is used with the ice, else the temperature may not be exactly zero.

If the indicator does not come to zero, the indicator may be adjusted to zero by rotating the zero adjusting screw in the

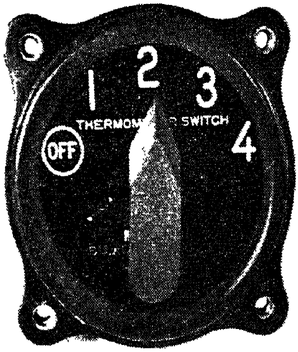


Figure 48. Front View of Four-Point Selector Switch

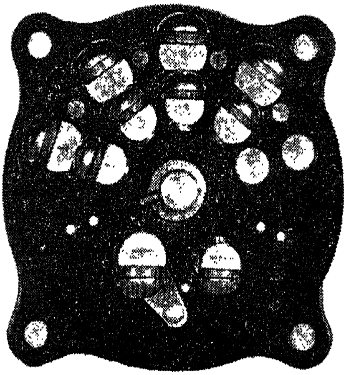


Figure 49. Rear View of Four-Point Selector Switch

(Lewis Engineering Co.)

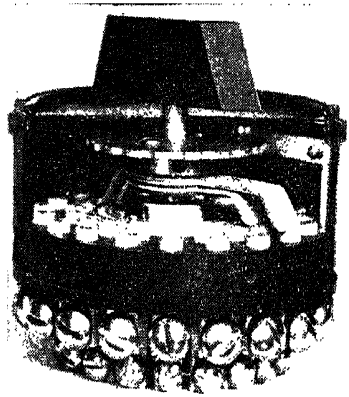


Figure 50. Cut-Away View of Eighteen-Point Switch

(Lewis Engineering Co.)

glass of the instrument by means of a small screwdriver. Rotate towards right or left until the instrument is on zero. If desired, the spark plug thermocouple may be immersed in boiling water when making the zero adjustment test instead of an ice bath, and in this case the instrument should indicate 100° C.

Another method of zero check is to disconnect the thermocouple lead from the thermocouple which is installed on the engine and connect a spare thermocouple to the thermocouple lead. Then immerse the thermocouple connected to the lead into an ice bath as above and the instrument should then indicate 0° C. This last suggested method eliminates removing the thermocouple from the engine which is sometimes laborious.

The above checks for zero adjustment are suggested for use in the field before installation in a plane where more elaborate equipment is not available for test.

After the instrument has been checked and adjusted to zero, replace all connections previously broken, and the indicator will then show correct temperature.

Inspection and Maintenance

After every fifty hours of flying, check the instrument as to its zero position. One method of doing this is to open the circuit at some convenient point, for example, at the thermocouple, or by removing one of the eye terminals from one of the studs on the back of the indicator. After the circuit has been so opened, the instrument should indicate the temperature of the cockpit. Temperature of the cockpit is found by placing a standardized mercury thermometer closely adjacent to the indicator and allowing sufficient time for the mercury thermometer to attain the same temperature as that of the indicator. The zero position of the indicator is then adjusted to agree with the thermometer reading.

When the individual lighting system ceases to function, replace with 3-volt lamp installed in the upper right-hand lug of the instrument. If after replacing the lamp, the lighting system does not function, the electrical circuit beyond the disconnect plug on the rear of the instrument should be checked.

Equipment Troubles and Remedies

Possible Cause	Remedies
No Reading, Either Permanent or Intermittent	
Break in lead.	Replace.
Break in thermocouple.	Replace.
Break in indicator.	Replace and return indicator to service station.
Break in switch.	Replace and return switch to service station.
Low Reading, Either Permanent or Intermittent	
Poor connection at indicator binding posts.	Clean and tighten.
Poor connection at thermocouple connectors.	Clean and tighten.
Poor connection at switch connectors.	Clean and tighten.
Poor connection in the indicator.	Replace and return indicator to service station.
Short circuit in leads.	Repair.
Short circuit at thermocouple.	Repair.
Short circuit at indicator binding posts.	Repair.
Zero corrector shift.	Reset.

Installation

Figure 51a shows the panel cut-out dimensions and the dimensions of the instrument proper.

Figure 51b shows the entire hookup from engine to panel. The thermocouple takes the place of the spark plug gasket. As the spark plug is tightened down the thermocouple rests against the cylinder head. The leads should be securely clamped to rigid members of the airplane at frequent intervals to prevent "swaying."

The magnetic shield Figure 51c is placed over the body of the instrument to localize the magnetic effect and thereby prevent its disturbing the compass.

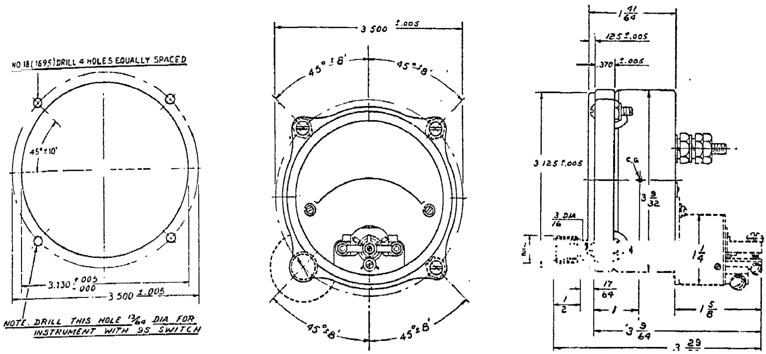


Figure 51a. Single-Engine Indicator Installation
(Lewis Engineering Co.)

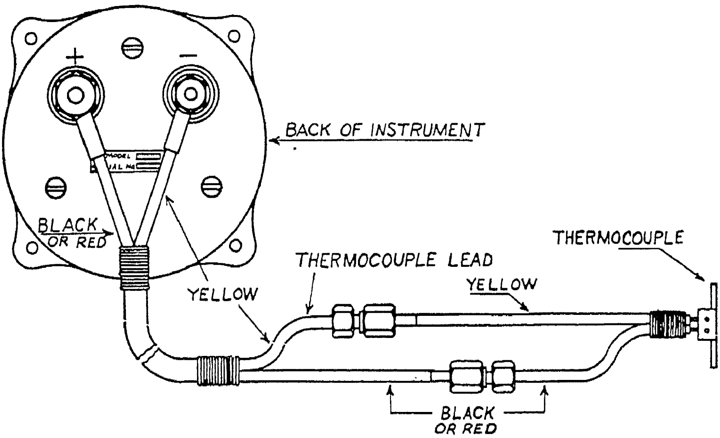


Figure 51b. Hookup from Engine to Panel

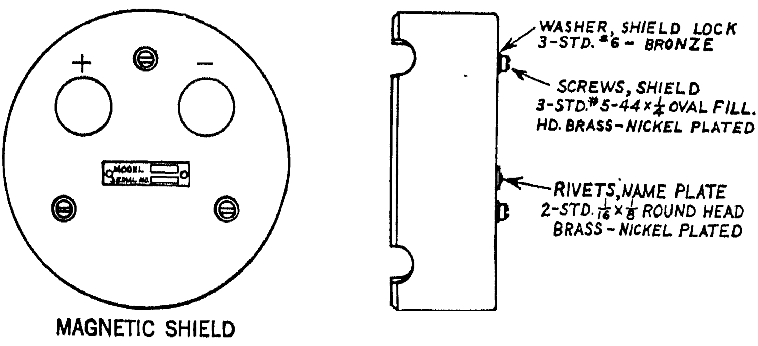


Figure 51c. Magnetic Shield

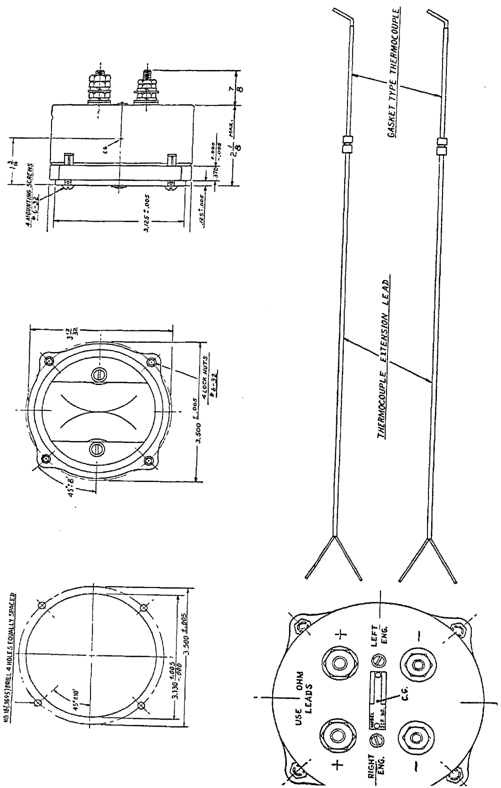


Figure 52. Dual-Engine Indicator Installation
(Lewis Engineering Co.)

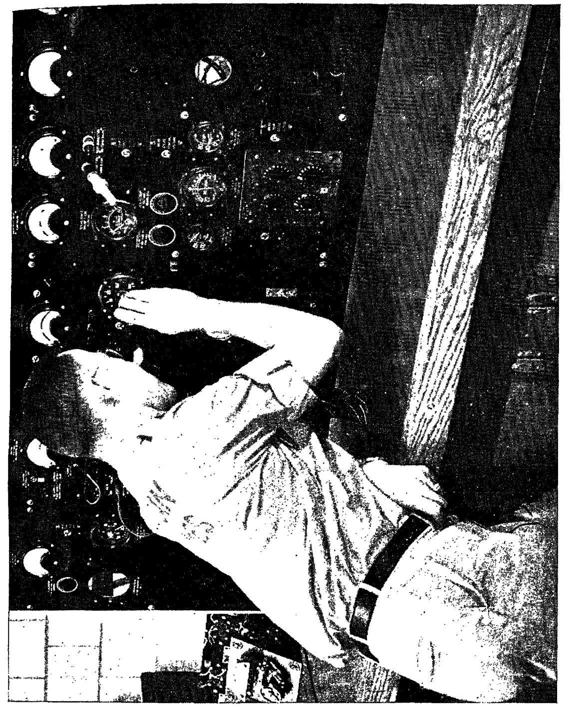


Figure 53. Electrical Instrument Test Panel
(American Airlines, Inc.)

American Airlines instrument technician making an adjustment on an electrical instrument on a modern electrical testing panel.

CHAPTER 11

CAMBRIDGE AERO MIXTURE INDICATOR

As gasoline will ignite only when mixed with air, it is the function of the carburetor of an airplane engine to mix air with the gasoline in the proper proportions for combustion. The ratio of the pounds of air admitted to the engine, to the pounds of gasoline to be mixed with it, is known as fuel-air ratio. The ideal fuel-air ratio is 1:13 (0.07) which means one unit of fuel to 13 units of air (in weight). A rich mixture, too much fuel and not enough air, will not give complete combustion and some of the fuel will be unburned. If there is too much air and not enough fuel, a lean mixture will result and the engine temperatures will be high.

Because no great loss of power results when the mixture is over-rich, there is a tendency to adjust carburetors on the rich side. Naturally this results in greater operating costs and a lesser cruising range.

It is just as easy, however, to obtain maximum power and maximum economy at the same time by using the aero mixture indicator as a guide.

To use the head temperature pyrometer as a guide in adjusting mixture controls is an uncertain and now obsolete practice. The tachometer indication method is likewise obsolete, having been rendered so by advent of automatic variable-pitch, constant-speed propellers. A proven means of indicating the fuel-air ratio, at any altitude, is provided by the aero mixture indicator. This instrument analyzes the exhaust gas and shows the result on an indicator scaled in terms of fuel-air ratio. It provides continuous indication. With this guidance the pilot can correctly set the mixture controls to obtain optimum performance of an engine under any given set of conditions.

It is a laboratory job to determine fuel-air ratio by measuring separately the quantities of gasoline and air as they are

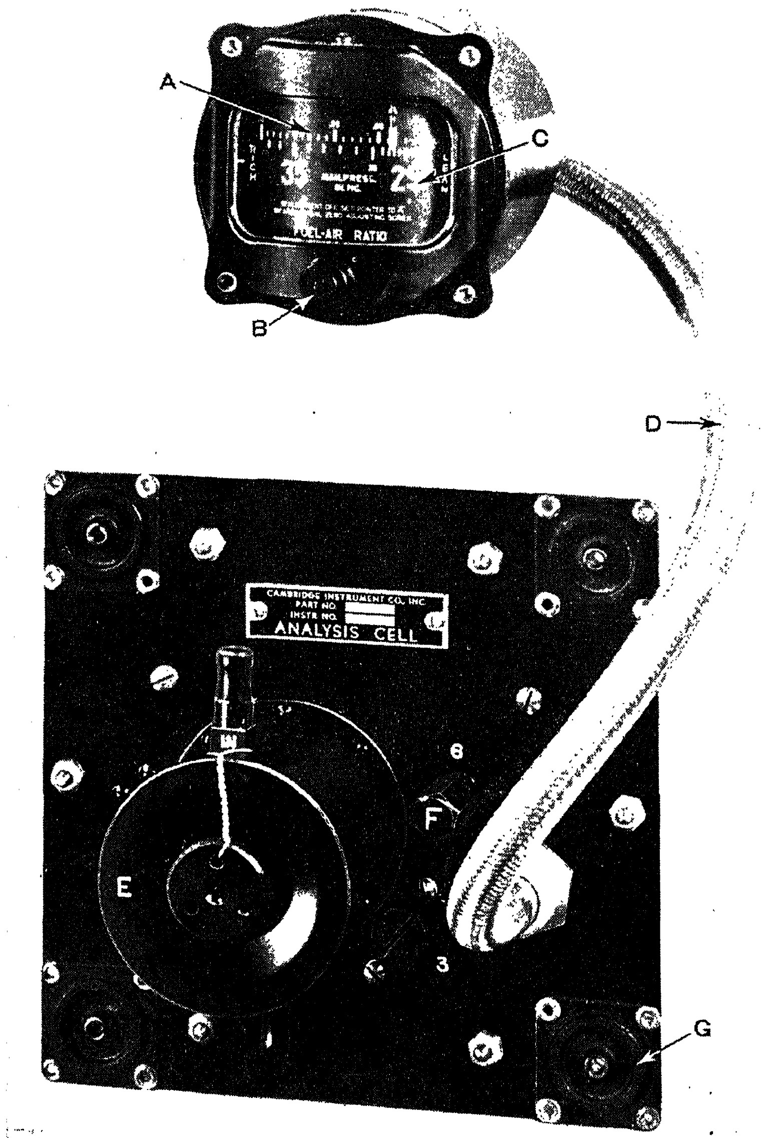
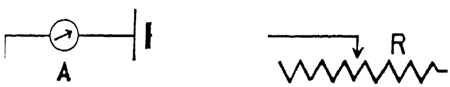


Figure 54. Cambridge Aero Mixture Indicator
(Cambridge Instrument Co.)

A—Fuel-Air Ratio Scale
B—Zero Adjustment
C—Manifold Pressure Scale
D—Electrical Wiring Conduit
E—Filter Chamber
F—Vapor Plug and Wick
G—Lord Rubber Shock Mounts

supplied to the carburetor. But the pre-combustion fuel-air ratio is just as accurately and far more simply determined by analysis of the exhaust gas *after* combustion has taken place.

The object desired in every case is to determine the efficiency with which the fuel is being burned in the engine—whether it be called fuel-air ratio, per cent combustibles, or per cent complete combustion. After all, they mean the same thing.



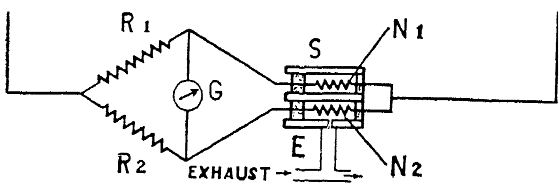


Figure 55. Diagram of the Principle of Operation of the Cambridge Aero Mixture Indicator
(Cambridge Instrument Co.)

Operation

With the Cambridge Aero Mixture Indicator, the method used is that of electrically measuring the thermal conductivity of the exhaust gas in comparison with a standard gas of known value—air. This method depends upon the fact that gases of different compositions have different values of heat transmission (thermal conductivity).

If a platinum wire spiral surrounded by a gas in a chamber is connected to a constant source of electric current, such as a dry battery, the temperature of the wire will rise until the heat dissipated from it is equal to the electrical energy supplied to it. This temperaure depends upon the ability of the gas surround-

ing the wire to conduct the heat away from the wire, in other words, the thermal conductivity of the gas. Accordingly, if we measure the temperature of the wire spiral, we know the thermal conductivity of the gas. The spiral temperature is readily determined by measuring its electrical resistance by the simple Wheatstone Bridge illustrated in Figure 55.

Two spirals of platinum wire having identical resistances, N_1 and N_2, are enclosed in separate cells S and E, these cells being encased in a solid metal block to insure their being at the same temperature. Each spiral forms one arm of a Wheatstone Bridge circuit, while two other identical resistances R_1 and R_2 complete the bridge. A definite electric current flows through the bridge heating the spirals, which in turn lose heat through the gases surrounding them, to the walls of the cells. A known or "standard" gas—saturated air—is trapped in cell S. The exhaust gas diffuses continuously into cell E. The difference in thermal conductivity of the exhaust gas and of the saturated air causes spiral N_2 to vary in temperature and, therefore, resistance as compared to spiral N_1. This unbalances the Wheatstone Bridges, producing deflections of galvanometer G, which is the indicator as shown in Figure 54. The extent of the deflections is a measure of the thermal conductivity. Therefore a direct reading can be obtained from the indicator of the fuel-air ratio of the burned mixture.

Figure 56 shows the general layout of a single-engine aero mixture indicator having two separate indicator units—one a duplicating indicator to furnish a duplicate indication for the second cockpit. This type is used in training planes. The inlet and outlet tubes lead to and are screwed into threaded flanges which are welded into the collector ring or exhaust pipe as shown in Figures 58, 59, and 60. The exhaust gas enters into the inlet tube, flows through the analysis cell and out the outlet tube. A 12-volt battery supplies the current for the electrical system. (2) is the mechanical zero setting screw used to set the pointer on "A" of the indicator, when the current is *off*. (3) is the electrical zero setting screw for setting the pointer on "A" with the current *on*. (6) is a vapor plug with a wetted wick producing saturated air (standard gas).

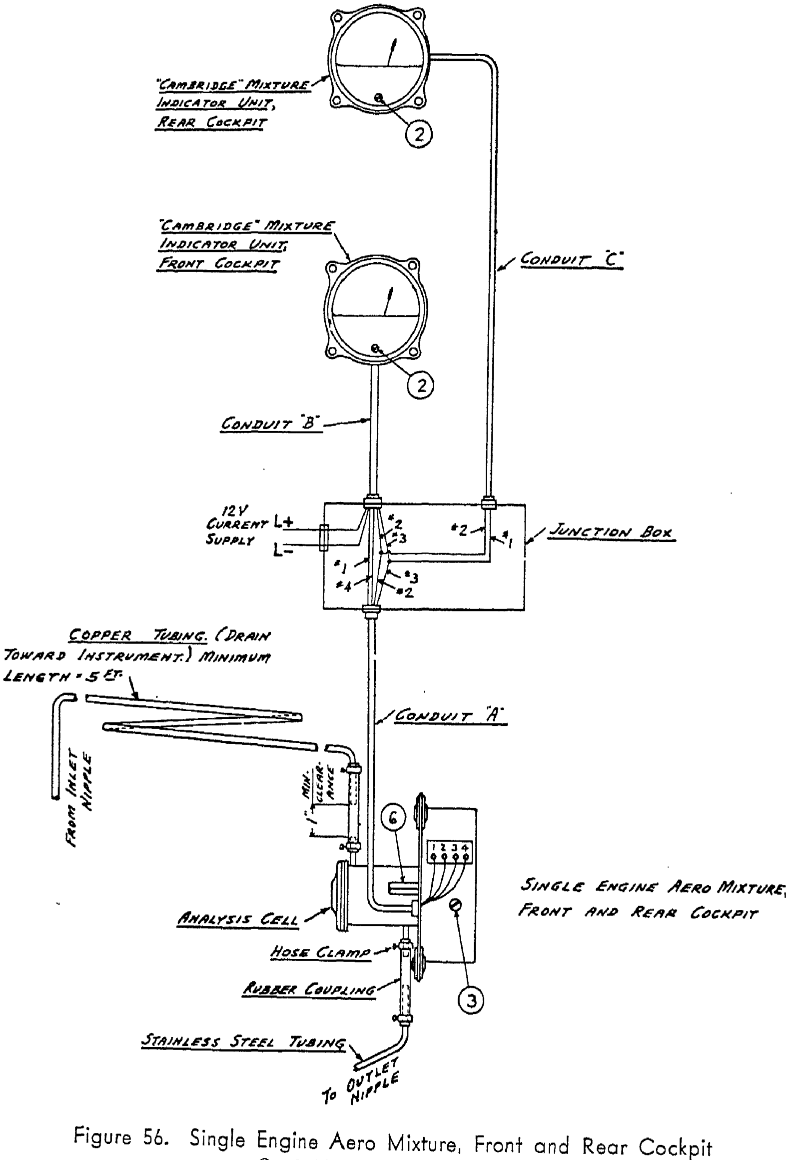


Figure 56. Single Engine Aero Mixture, Front and Rear Cockpit
(Cambridge Instrument Co.)

Flying with the Aero Mixture Indicator

After the engine is started the indicator will normally show response to a change in mixture in about 5 or 6 seconds, and elapse of this time should be allowed before taking a reading. The current should be left on continuously while the plane is in use.

The instrument may be relied upon for accuracy with mixtures leaned out to a maximum of 0.068 fuel-air ratio. When leaning out, should the pointer, in approximately this range, reverse and move back towards the "A" point, it is indication that the mixture is lean beyond the range of the instrument, and should be made richer.

A correct fuel-air ratio indication should not be taken as lessening the importance of the head temperature indicator in guarding against overheating the engine. Even though the engine manufacturer's recommendations with respect to mixture ratio are being observed, the head temperatures should receive the usual close attention. Should detonation occur, the pointer of the mixture indicator will move erratically, generally towards the rich end of the scale.

To facilitate adjustment to the correct mixture for different values of horsepower developed by the engine, a manifold pressure scale (see Figure 54) is employed in addition to the fuel-air ratio scale, in which case the two scales are properly correlated in accordance with the recommendations of the engine manufacturer. It should be understood that the mixture indicator does not measure manifold pressure, the scale being used solely for the purpose of reference. In using, the operator observes the existing pressure from the manifold pressure gauge and then adjusts the mixture to cause the pointer of the mixture indicator to move to the corresponding pressure, whereupon the optimum fuel-air ratio is obtained. In other cases segmented scales are employed, wherein segments marked "Take-Off," "Cruise Climb," "Cruise Level," etc., are properly placed opposite the fuel-air ratio desired for such operations. Where such correlation data are not available, the instrument is scaled in fuel-air ratio only, and the general instructions on

proper mixtures, furnished by the engine manufacturer, should be followed.

When carburetor heat is applied, it becomes necessary to lean out the mixture to restore the former fuel-air ratio. Conversely, when the heat is turned off, it is necessary to enrich the mixture, but be sure to make the mixture richer before the heat is turned off, else the mixture might become too lean.

If the engine is equipped with a carburetor that does not automatically compensate for variations in atmospheric pressure, it is necessary when descending to gradually richen the mixture. When 500 feet above the airport the mixture should be set at full rich regardless of the type of carburetor.

Inspection and Maintenance

Routine Servicing. It is necessary periodically to perform the service operations enumerated below. While it is suggested that this be done every 100 hours, such routine may be adjusted to the regular inspection periods of the particular operator.

The sampling nipples and gas line should be cleaned out and joints tightened where necessary. A drill of the proper size welded to the end of a length of tachometer shaft forms a good clean-out tool, or the gas line may be removed from the plane and the carbon deposit burned out with a blow torch, which will also serve to anneal the line.

Renew rubber shock mounts of the analysis cell where necessary (Figure 54).

Remove filter wool and wash with gasoline or replace with new wool if necessary. Also clean out filter chamber.

Test the indicator unit for pointer stiction by noting the pointer position with the current off. Then turn the current on to cause a movement of the pointer (it may be necessary that there be exhaust gas in the cell to cause this movement), and then off again. The pointer should return to its original position. If it does not and the indicated stiction is greater than 0.002 fuel-air ratio, the unit should be repaired at the earliest opportunity.

Wet the wick in the vapor plug (No. 6, Figure 56), make sure the breather hole (size #80 drill) in the plug is open, and replace.

Mechanical Zero Adjustment. With the current off, the pointer should stand at "A" on the scale. If it does not, adjust to this position by means of the zero screw on the indicator front.

Electrical Zero Adjustment. The position of the pointer on the electrical zero is the same as on the mechanical zero.

To Check. (a) First see that the mechanical zero is properly set.

(b) Wet the wick in the vapor plug (No. 6, Figure 56) of the analysis cell.

(c) Remove cover and steel wool from filter chamber of the analysis cell, allowing time for any residual gas to be displaced by fresh air. Then place inside this chamber a clean, wetted rag that has been slightly wrung out, and replace the cover.

(d) Now, with the current on, allow the instrument to stand thus for about 30 minutes, at the end of which time the pointer should stand at "A" on the scale. If it does not, adjust to this position by means of rheostat (No. 3, Figure 56) in the analysis cell. The wetted rag should then be removed from the filter chamber and the steel wool and cover replaced. When replacing the wool, push in sufficiently to clear the opening of the inlet pipe.

Trouble Shooting

Augmenting the information contained in the preceding section, the following may be of assistance in the event of trouble.

If no response or "kick" of the pointer results upon switching the current on:

(a) There may be an open circuit in the current supply or galvanometer wires.

(b) The ballast tube in the indicator unit may be burned out.

If indicator pointer deflects violently to one end or the other end of the scale when the current is switched on:

(a) The wires may be connected up wrong or there may be a ground. Check all connections and if in doubt "ring out" all wires between the units to see if they are rightly connected. Make sure no strands of wire are touching adjoining terminals or are grounded. Test for grounds in the usual manner, disconnecting both battery leads. If a ground is not found in the wiring connecting the units, it may be traced to the individual unit by disconnecting the wires to each unit in turn.

(b) There may be an open circuit in the bridge spirals. To verify that the trouble is in the analysis cell, a spare cell should be installed and the instrument checked.

If the instrument does not properly respond to a change in mixture ratio:

(a) The analysis cell may not be getting a sample of the exhaust gas, due to the inlet sampling nipple being improperly placed; water or ice in the sampling system; clogged gas line or filter; back pressure on the gas outlet from the cell. These points should be checked and corrected where necessary.

(b) The galvanometer wires may be reversed where connected at the analysis cell, which would cause the indicator pointer to move in a direction opposite to normal.

(c) There may be pivot stiction in the galvanometer or there may be some obstruction preventing free movement of the pointer.

(d) The mechanical or electrical zero may be off.

Installation

The Analysis Cell. The dimensions of the analysis cell are shown on Figure 57. It should be mounted on suitable brackets adjacent to the engine; in a single-engine plane on the fire wall or other convenient location (but not within the cabin where a possible gas leak would be dangerous), and in a multi-engine

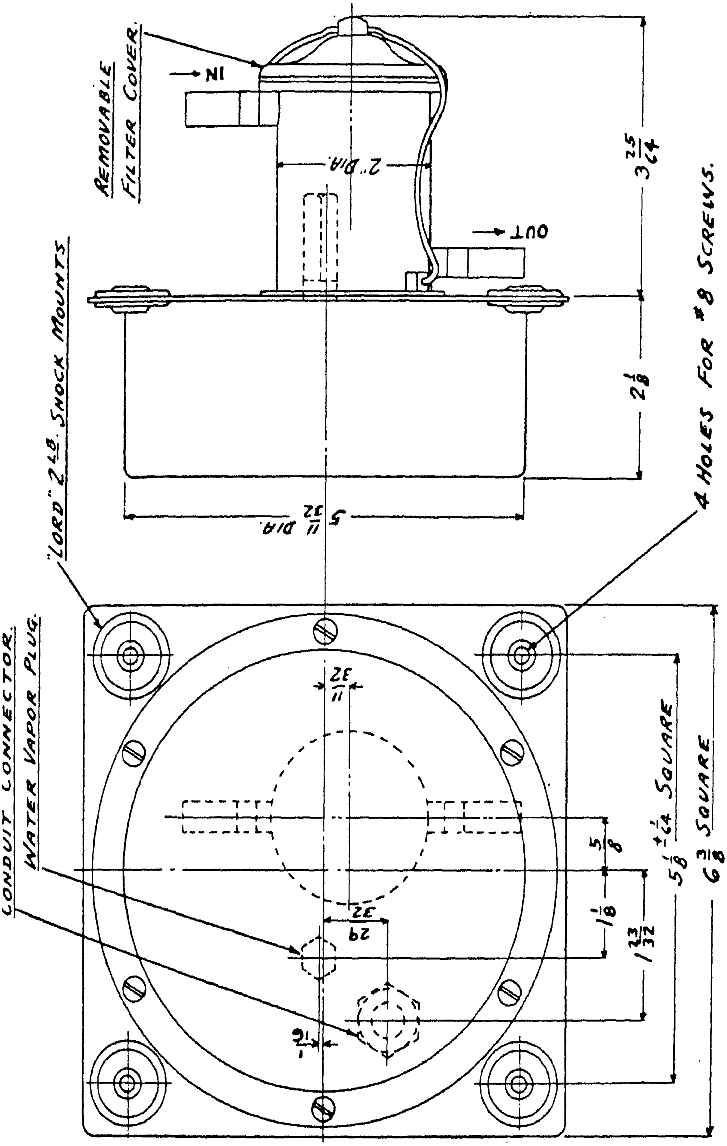
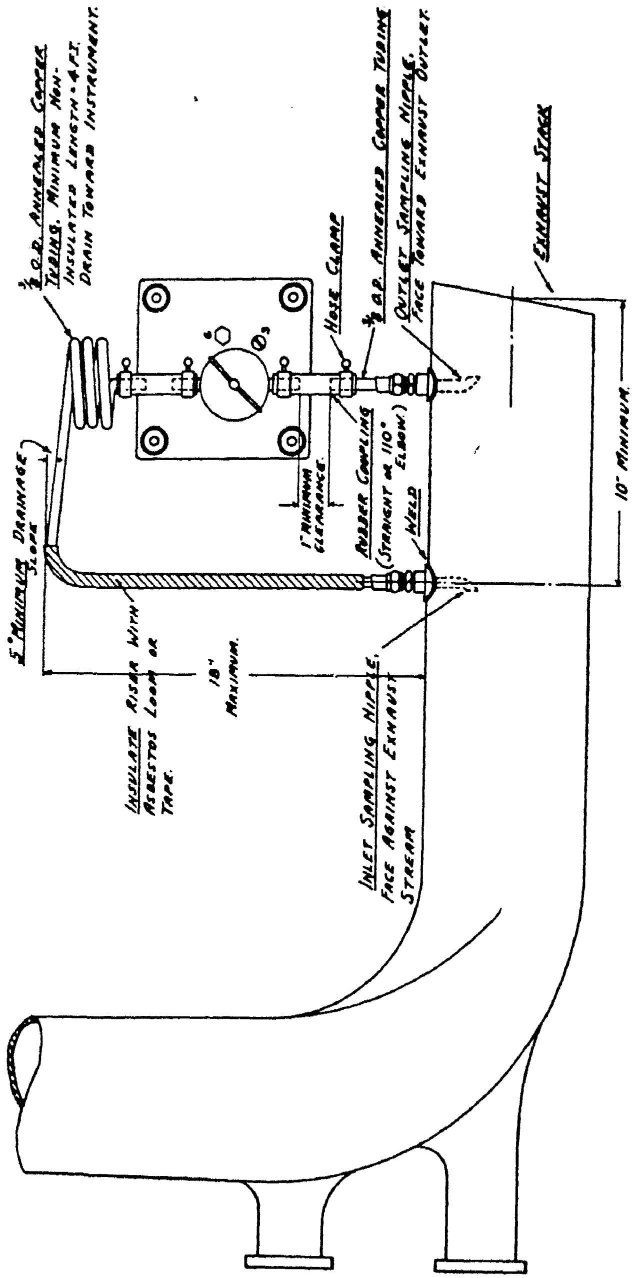


Figure 57. Cambridge Aero Mixture Indicator Analysis Cell
(Cambridge Instrument Co.)



Sampl Collecto and Sta

plane at some suitable place in the nacelle. To drainage of condensate from the cell, it should be that the inlet pipe points directly upward. Care should be taken that no obstructions adjacent to the cell prevent its free movement within the limits of the rubber shock mounts.

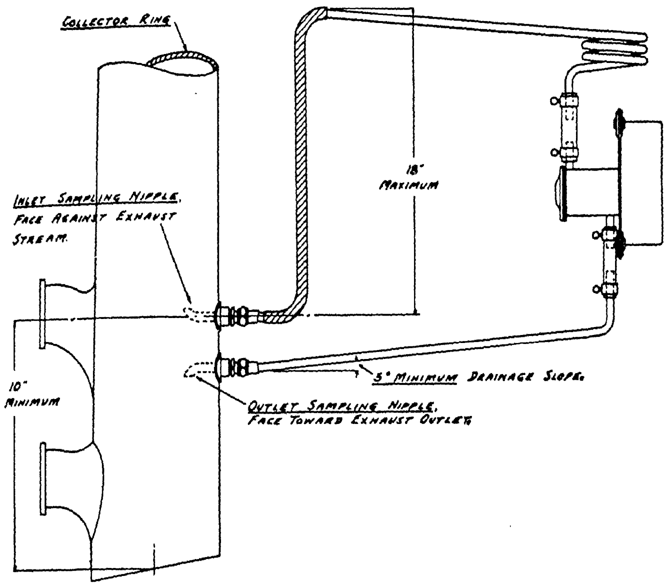


Figure 59. A Second Method of Installing Sample Nipples in Collector Rings and Exhaust Stack

Gas Sampling System. 3, 59, and 60 show pre- gas ing arran for cases where te the

underneath and eaded flanges which are welded to the tail pipe or ring, t nipple being turned upstream and the outlet nipple downstream, and ⅜″ copper tubing is connected to the nipples by flange fitt d to the cell by means of 3 sh revent transmitted vibrations should be, in the joints, a

space of at least 1″ between the end of the tubing and the inlet and outlet pipes of the cell.

Good drainage of condensate from the gas sampling system is essential to a satisfactory flow of gas through the cell, and it is therefore necessary to keep the gas at a temperature above

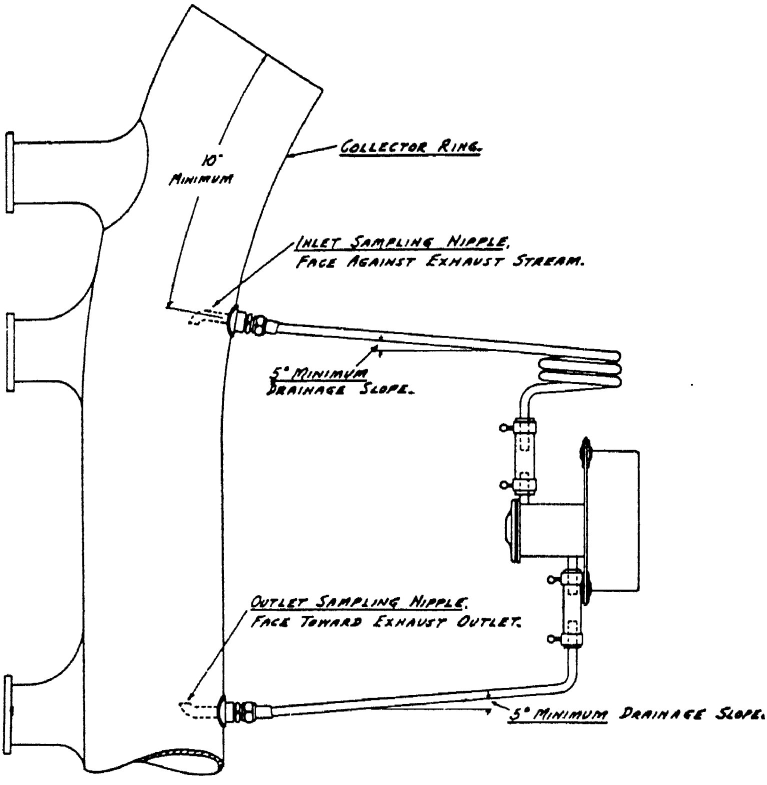


Figure 60. A Third Method of Installing Sample Nipples in Collector Rings and Exhaust Stack

the dew point in any section of the line where the gas flows upward, otherwise the line might become water-locked, thus stopping gas flow. To this end, the upward leg of the line should not be more than 18″ in length and well insulated with asbestos loom or tape. On the other hand, to assure the desired water saturated gas sample in the cell, it is necessary to have

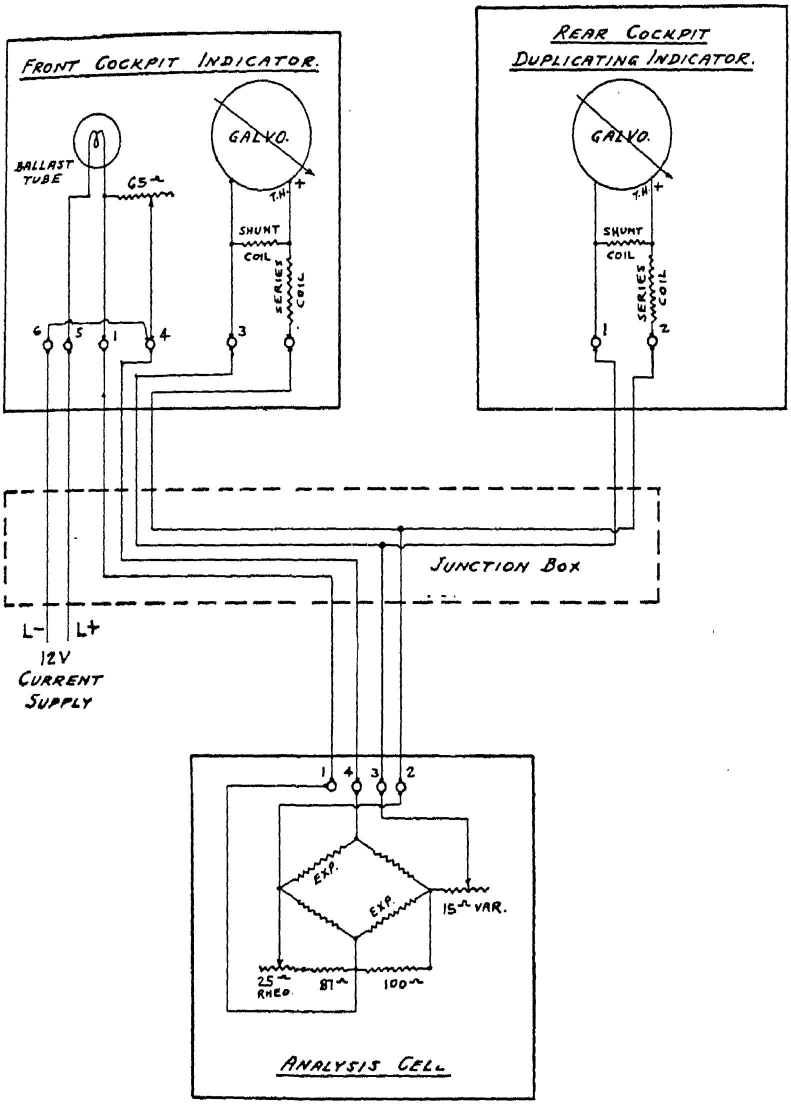


Figure 61. Single-Engine Wiring Diagram

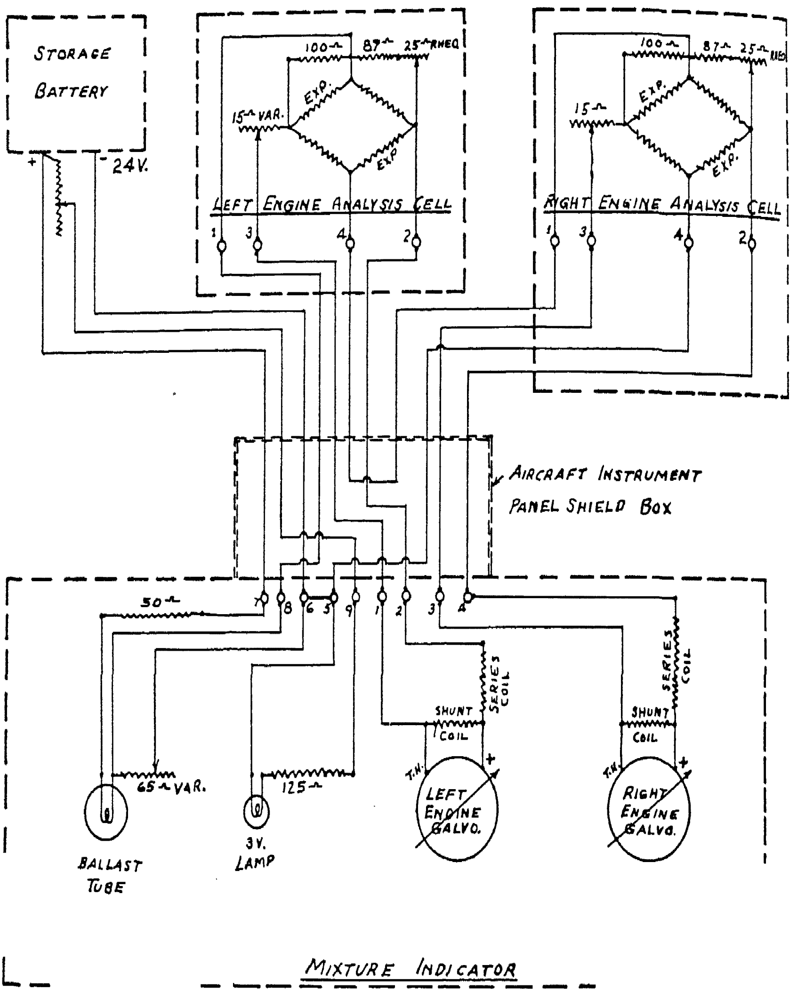


Figure 62. Dual-Engine Wiring Diagram

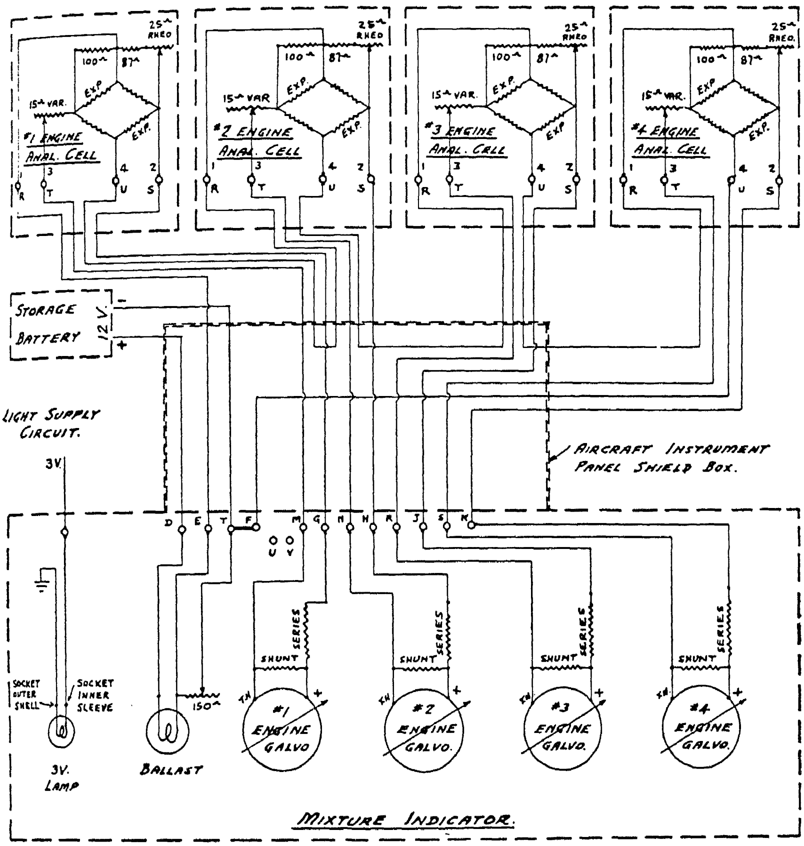
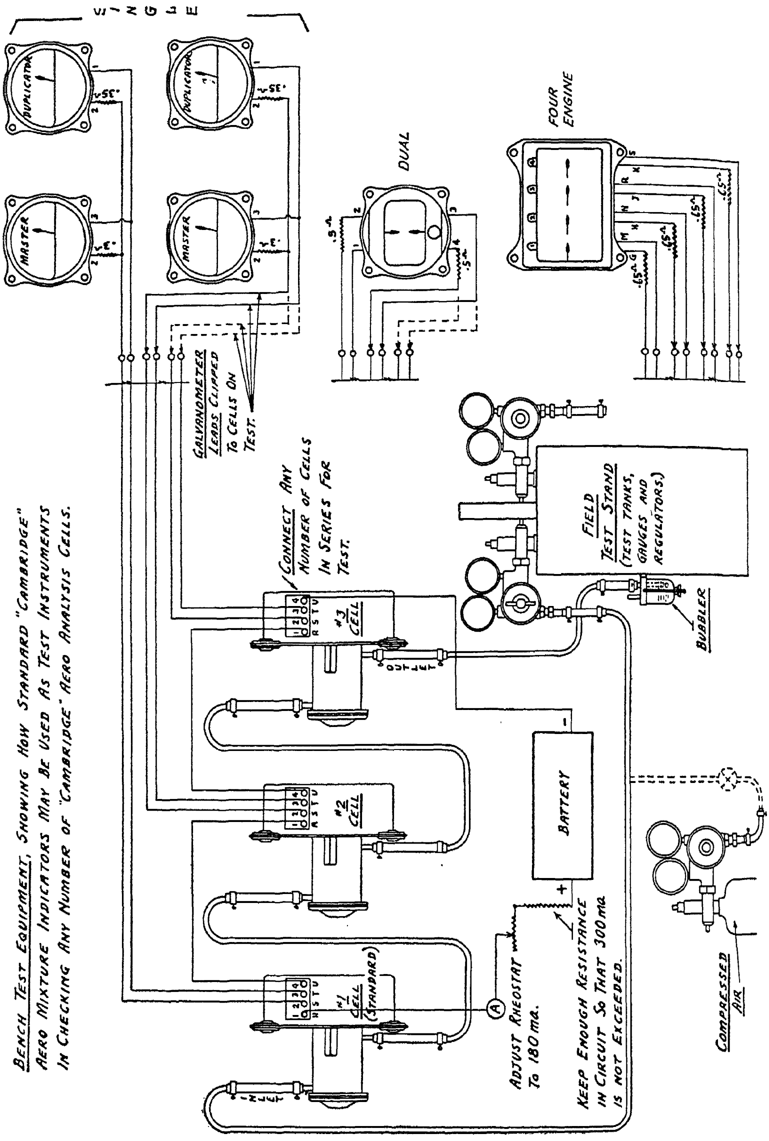


Figure 63. Four-Engine Wiring Diagram



Bench Test Equipment, Showing How Standard "Cambridge" Aero Mixture Indicators May Be Used As Test Instruments In Checking Any Number of "Cambridge" Aero Analysis Cells.

not less than 4 feet of bare tubing between the highest point in the line and the inlet of the cell for cooling purposes. This section of the line may take the form of a coil, but there should be no low spots in the coil that would form a water trap. The temperature in the filter chamber of the cell should not exceed 125° F. nor should any portion of the gas sampling system be exposed to freezing temperatures, as ice will form from the condensate and stop the gas flow. In cases of extreme heat the cell may be cooled by a blast tube, and in cases of extreme cold, correction may be made by partially insulating the cell and waste line.

Figures 61, 62, and 63 show the electrical wiring of single, dual, and four-engine indicators.

CHAPTER 12

CENTRIFUGAL AND ELECTRIC TACHOMETERS

1. Centrifugal Tachometers

The centrifugal tachometer indicates the crankshaft speed in revolutions per minute of aircraft engines. Usually the gearing is such that the tachometer is driven at one-half engine speed but the dial is calibrated to read actual speed of the engine.

A flexible driveshaft triple reverse wound, encased in a flexible housing, is connected at one end to the instrument and at the other end to a fitting provided in the engine. As the crankshaft revolves it revolves the flexible driveshaft which in turn causes the mechanism to function as herewith explained. See Figure 67 for schematic labeled drawing of Kollsman tachometer.

Operation of Kollsman Tachometer

The tachometer consists of a lower, or governor, mechanism (A) and an upper, or multiplying, mechanism (B), both mounted in a die case mechanism housing (C). The lower mechanism with its two flyweights (D) and (D′) is driven directly without intermediate gearing by the flexible shaft connected to the standard S.A.E. fitting shown with dust cap (E) in place. Two flat springs (F) restrain the movement of the flyweight arms (G). These springs also serve to restore the weights to their original position when the speed is reduced. Two counterweights (H shown) stabilize the governor system.

The movement of the flyweights is transmitted through a plunger (I) and rocking-shaft (J) to the multiplying mechanism. Sector assembly (K) in turn transmits the movement to

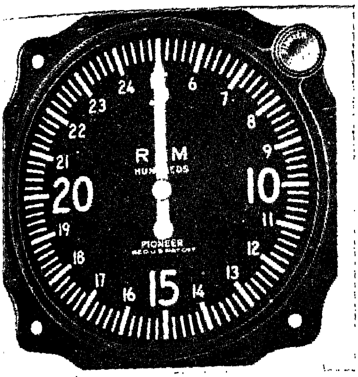


Figure 65. Pioneer Type 2011-1A1
(Pioneer Instrument Division of Bendix Aviation Corp.)

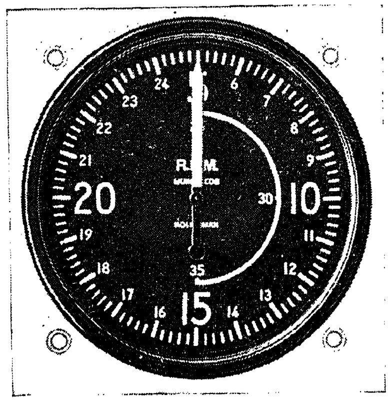


Figure 66. Kollsman Type 170-01
(Kollsman Instrument Division of Square D Co.)

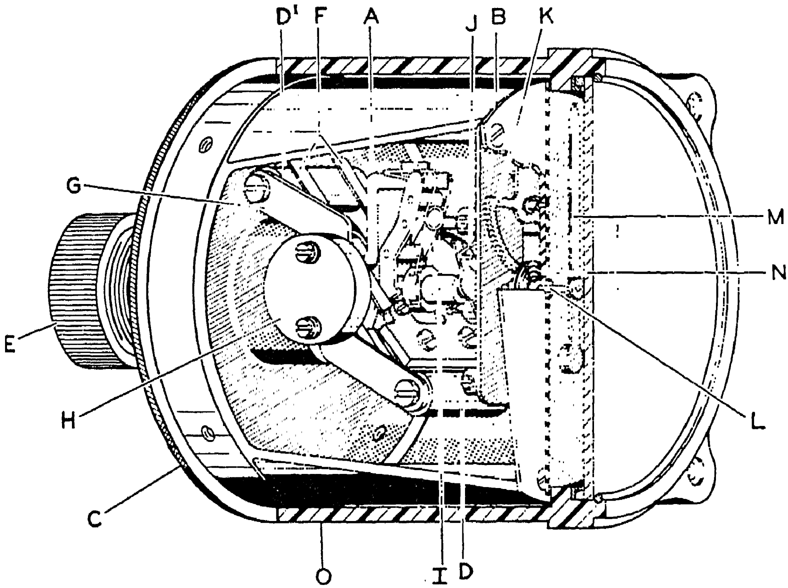


Figure 67. Schematic Drawing Kollsman Type 170-01
(Kollsman Instrument Division of Square D Co.)

the hand-staff (L) and thus to the pointer (M) which indicates in r.p.m. Hairspring (N) removes the backlash from the upper mechanism.

The bakelite case (O) secured to the mechanism housing by four screws encloses the entire mechanism.

The Pioneer centrifugal tachometer operates in much the same manner.

Flying with the Tachometer

The airplane depends on its engine for actual support in the air and for propulsion through the air. The tachometer indicates any engine irregularity by showing a loss of revolutions per minute when the throttle is at a fixed setting.

The correct throttle setting, and therefore a definite reading of the tachometer, may be used to adjust the engine speed to its best economy.

Each engine has a definite speed at which the wear is at a minimum. By experiment this speed should be determined and the airplane flown at that r.p.m.

Usually, the engine is warmed up at about 900 r.p.m. until the oil temperature gauge indicates the correct degree of warmth. Before take-off it is general practice to lock the brakes and give the engine full throttle. If the engine fails to revolve at the maximum ground (r.p.m.) it is definite proof that it is not functioning properly and should be checked.

Some of the possible troubles of the tachometer and the causes are listed following:

Trouble	Cause
(a) Failure of pointer to return to zero.	Dirt in the mechanism. Loose hand.
(b) Sluggish hand.	Dirt in the mechanism. Tight rocking-shaft pivots.
(c) Noisy bearings.	Worn or pitted bearings.
(d) Excessive pointer oscillation.	Binding driveshaft.
(e) Sticking hand.	Binding on the dial. Binding on dial screws.
(f) Lighting system failure.	Burned-out lamp. Broken contact.

Test Apparatus

A motor-driven comparative type test apparatus used for testing the calibration of tachometers against a known standard is shown in Figure 68.

This type consists essentially of an AC or DC motor which drives a tachometer outlet spindle through a variable speed friction arrangement. A spring mounted on the end of the rotor shaft holds the disc under constant pressure. This disc in turn drives the spindle through a special leather wheel. The spindle is mounted on two sets of ball bearings which insure smooth operation and long life. A tachometer outlet is provided as an integral part of both ends of this drive spindle. The speed is controlled by a handle which through a long screw varies the effective driving ratio of the disc and wheel by moving the motor fore and aft on a track.

The Pioneer master tachometer is of the centrifugal type and has a scale graduated every 20 r.p.m. from 500 to any practical

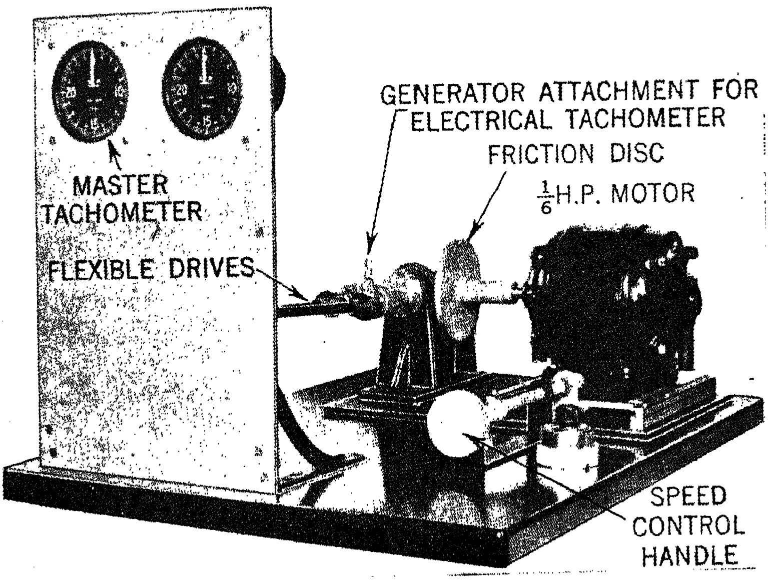


Figure 68. Pioneer Tachometer Test Apparatus
(Pioneer Instrument Division of Bendix Aviation Corp.)

maximum figure desired, usually 2,500 or 3,000. Both the master tachometer and the one being tested indicate double speed of the motor, since the standard tachometer reduction is 2:1.

A 1/6 hp. constant speed electrical motor is used for the driving power.

A double tachometer outlet connection is provided on one end of the driving spindle together with two 4-foot flexible shafts for connection to the instruments. A single outlet on the other end of the spindle permits attachment of the generator unit of an electric tachometer or mounting a multiple adapter for testing several additional instruments at the same time.

Directions for Tests

Attach the tachometer for test to the stand and connect the flexible shaft. The motor drive should be in the neutral position when the motor is started. The speed control handle should be turned slowly until the Master Tachometer begins to indicate. Regulate at constant speed according to the master and compare the instrument under test. Continue to increase the speed gradually and compare over the entire range. Then reduce the speed and check back to zero. The stand should be tapped lightly at each reading to eliminate any friction errors.

Sometimes when more accurate readings are necessary a device known as the stroboscope is used. In such tests the master tachometer is the "Master" and the stroboscope is the "vernier." It is attached to the shaft that drives the instrument under test and the "master" tachometer and all three rotate at the same speed.

It makes use of the fact that the human eye holds an image for approximately 1/20 of a second. If therefore before the expiration of this time period a second image is shown differing only slightly from its preceding one, the eye will see the second impression as a change from the first, not as a separate image. When a succession of images are seen, each differing only slightly, the eye will see them as movement, not as individual changes.

In the stroboscope this principle is used by rotating a series of holes in front of a neon lamp which is going on and off at a preset frequency, for example, 50 times per second or 3,000 times per minute. If the disc is rotated at 3,000 r.p.m., these holes will all appear to be stationary because it is the light image that we see, and as the disc is rotating at the exact frequency of the light, no change of position is noticeable. The light is out when the disc is in motion and appears only at the times when the holes are in the same position as at the previous period of illumination. If, however, the speed of rotation is slightly slower or faster than 3,000 r.p.m. the holes will appear to have motion, the speed of which is proportional to the amount of displacement.

But let us suppose that there are 30 holes spaced radially and evenly around the disc and that the disc is rotating at 100 r.p.m. Under these conditions as 30 is a multiple of 3,000 to the factor of 100, then it follows that there will still be no relative change of position as far as the light path is concerned. Were we to mark one hole it would be noted that the light would have appeared 30 times before the hole reappeared in its original position again. It would have appeared at an angular displacement of 12° on the disc at each appearance ($360 \div 30$), but as there is a hole at each 12° on the disc and as they are radially spaced and of equal size we cannot judge which hole is appearing before the light and therefore can discern no movement.

We can therefore judge any speed which is a multiple of 100 r.p.m. by using a disc with 30 holes and a light with a frequency of *3000 cy. per min.*

Other speeds may be judged by working out other combinations as follows:

60 holes	$3000 \div 60 = 50$
30 "	$3000 \div 30 = 100$
6 "	$3000 \div 6 = 500$
5 "	$3000 \div 5 = 600$
4 "	$3000 \div 4 = 750$

60 holes will judge any speed and multiple of 50.
30 holes will judge any speed and multiple of 100.
6, 5, 4, will judge multiples of 500, 600, and 750 in the same manner.

A table may be worked out and would appear as follows:

Speeds	Circle of Holes That Appear Stationary
100	60–30–x–x–
200	60–30–x–x–x–
600	60–30–x–5–x
1,000	60–30–6–x–x
750	60– x–x–x–4
1,500	60–30–6–x–x
450	60– x–x–x–x
1,250	60– x–x–x–x

The following test specifications pertain only to Pioneer Type 2011. For all other types and makes the manufacturer's test manual should be consulted.

Whenever the pressure and temperature existing at the time of the test are not specified definitely, it is understood that the test is to be made at atmospheric pressure (approximately 29.92″ of mercury) and at room temperature (approximately plus 20° C.). When tests are made with atmospheric pressure or room temperature differing materially from the above values, proper allowance shall be made for the difference.

The instrument shall be tested in an upright vertical position and shall be lightly vibrated or tapped before a test reading is taken. In the following tests the speeds given are the speeds at which the instrument is operated and correspond to one-half the indicated speeds. The test shall be made by subjecting the instrument to the speeds specified to produce these readings, first with speeds increasing, then with speeds decreasing. With speeds increasing the speed shall be brought up to, but shall not exceed, the speed specified to give the desired reading, and with speeds decreasing the speed shall be brought down to, but shall not fall below, the speed specified to give the desired reading.

To facilitate adjustments, the case is usually left off until the instrument has been calibrated. The mechanism is then mounted in the case and the glass and the snap ring are added. A final check is made then to determine the tightness of external screw-heads and the general overall cleanliness of the instrument.

	Tolerance		
Standard r.p.m.	Range: 2,000	2,500	3,000
500	50	50	50
600	50	50	50
700	40	40	40
800	40	40	40
900	30	30	30
1,000	30	30	30
1,100	20	20	20
1,200	20	20	20
1,300	20	20	20
1,400	20	20	20
1,500	20	20	20
1,600	20	20	20
1,700	20	20	20
1,800	20	20	20
1,900	30	20	20
2,000	30	20	20
2,100		20	20
2,200		20	20
2,300		30	20
2,400		30	20
2,500		30	30
2,600			30
2,700			40
2,800			40
2,900			50
3,000			50

Installation

The dimensions in Figures 69 and 70 will serve as a guide for the listed types.

The driveshaft should be so installed that it makes no bends with a radius less than 6″. Before finally connecting the shaft to the engine the system should be tested by turning the shaft with the fingers from the engine end. If the driveshaft does not turn freely, the trouble should be eliminated before final connection.

The driveshaft housing should be rigidly clamped each 36″ to prevent "swaying." The instrument end of the driveshaft should be higher than the engine end to prevent drainage of oil into the instrument.

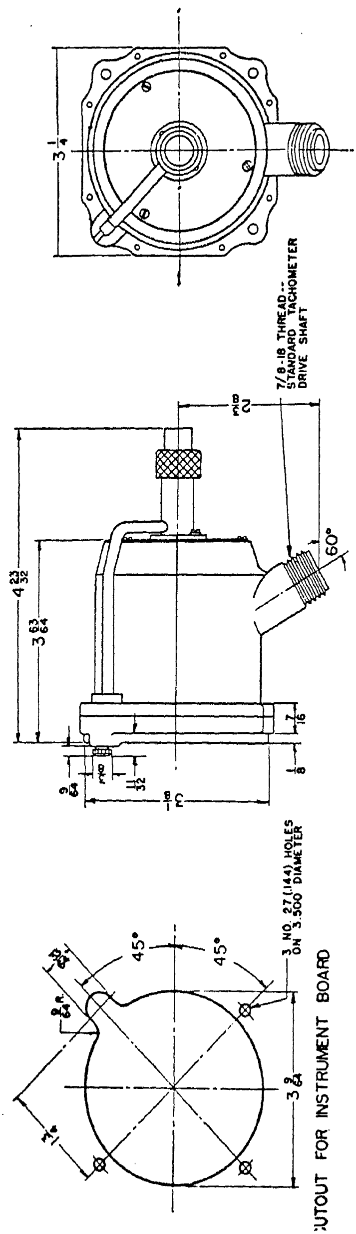


Figure 69. Installation Drawing Pioneer Type 2011-1A1
(Pioneer Instrument Division of Bendix Aviation Corp.)

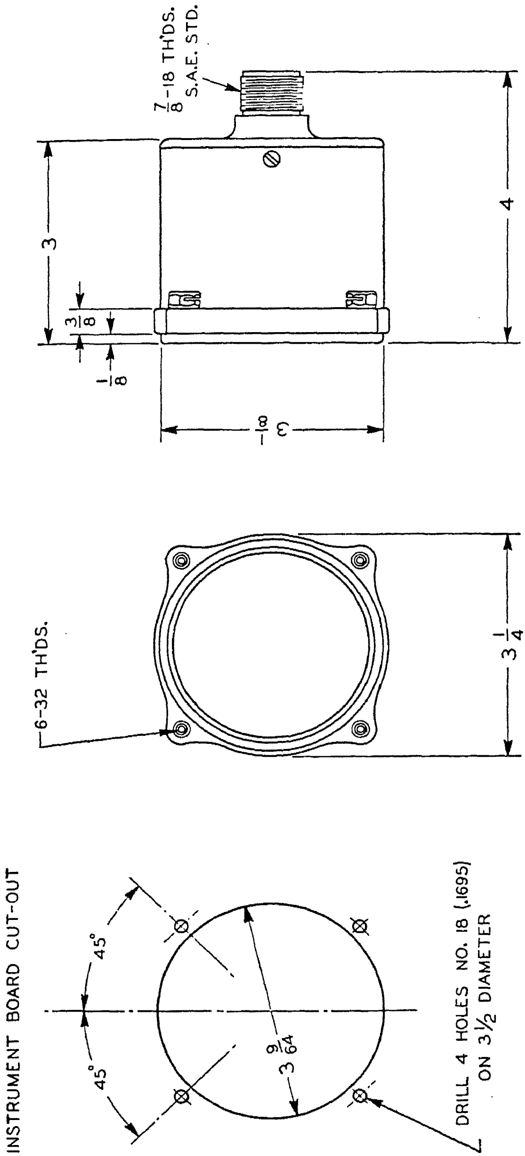


Figure 70. Installation Drawing Kollsman Type 170-01
(Kollsman Instrument Division of Square D Co.)

Figure 71. Pioneer Sensitive Tachometer

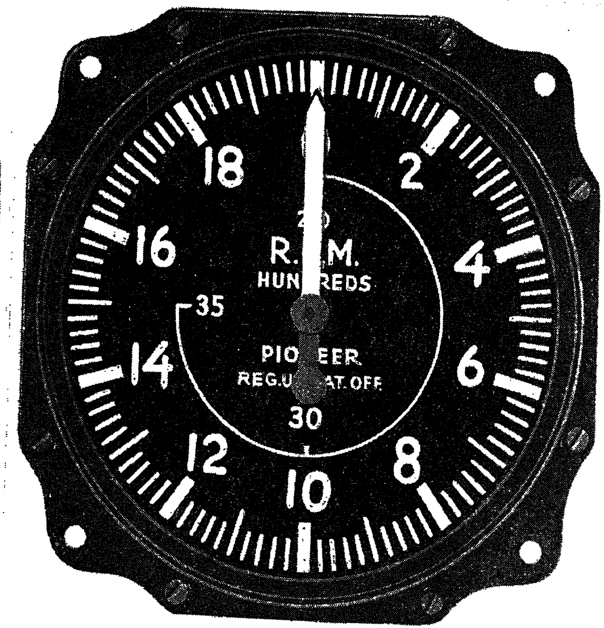


Figure 72. Pioneer Standard Tachometer

(Pioneer Instrument Division of Bendix Aviation Corp.)

2. Electric Tachometers

The discussion of electric tachometers is confined to the Kollsman types shown here. Figure 73 illustrates the standard type and Figure 74 the sensitive type of Kollsman electric tachometer. A schematic drawing of the sensitive tachometer indicator is given in Figure 75, while Figure 76 presents a schematic drawing of the Kollsman tachometer generator.

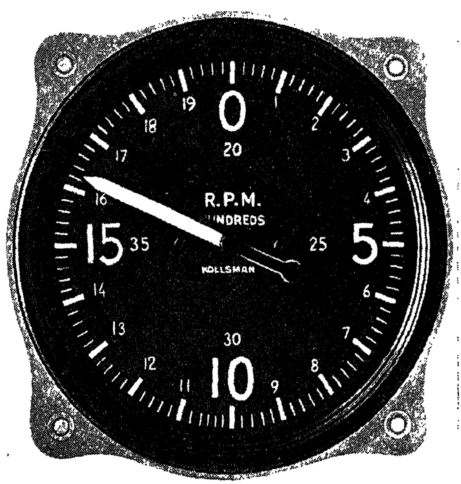


Figure 73. Kollsman Standard Type
(Kollsman Instrument Division of Square D Co.)

Operation

Tachometer Indicator. The indicator, which is mounted on the instrument panel, consists of a small synchronous motor (A) and a magnetic tachometer unit (B). The motor consists of a stator coil (C) and a rotor (D). Attached to the shaft of the rotor is a magnet (E). A drum (F) is attached to the hair-spring shaft and its rotation is restrained by hairspring (G).

The movement of the drum as it is pulled around by the magnet against the force of the hairspring is transmitted to the gear train (H) and is indicated in r.p.m. of crankshaft speed on

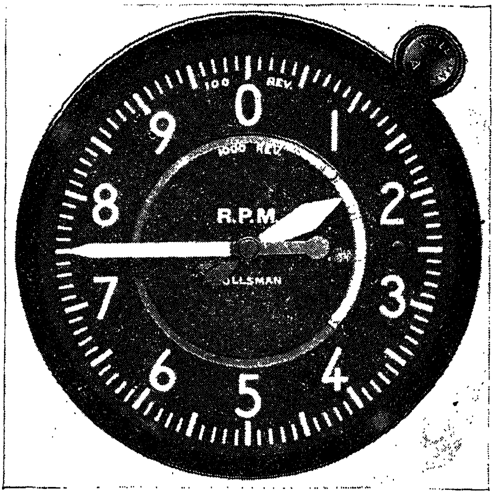


Figure 74. Kollsman Sensitive Type

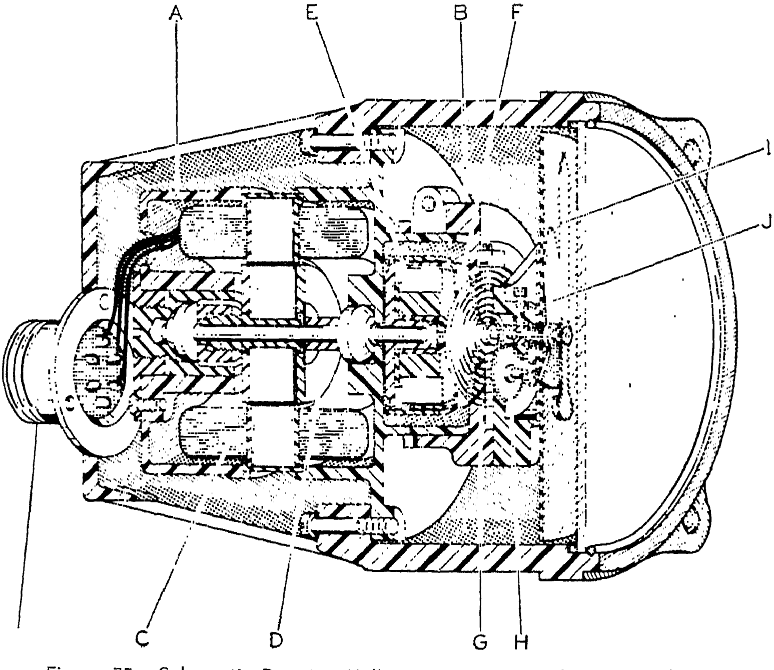


Figure 75. Schematic Drawing Kollsman Sensitive Tachometer Indicator
(Kollsman Instrument Division of Square D Co.)

the dial by pointers (I) and (J). The single-pointer indicator does not include the gear train (H).

Connections from the generator are made by three wires to the motor unit of the indicator at (K).

Tachometer Generator. The tachometer generator consists of a rotor (A) turned by shaft (B) inside of stator coil (C). Driven by the tachometer outlet driveshaft on the engine, the rotor will rotate at the same speed as the tachometer drive.

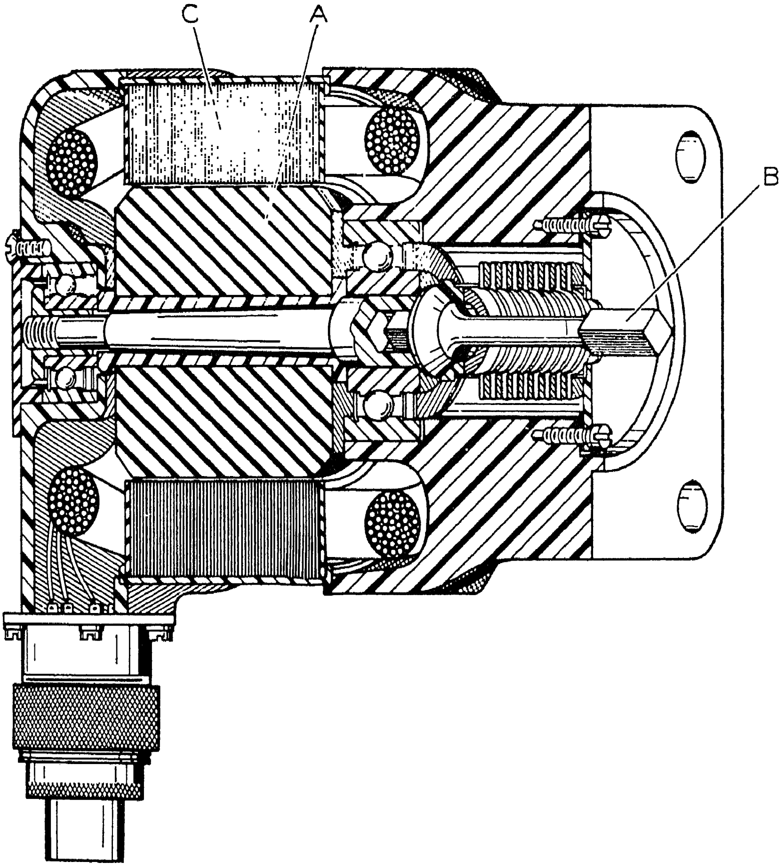


Figure 76. Schematic Drawing Kollsman Tachometer Generator
(Kollsman Instrument Division of Square D Co.)

Test Specifications

Applicable to Kollsman electric tachometers only.

The indicator shall be tested in an upright vertical position and shall be lightly vibrated or tapped before a test reading is taken.

Scale Error Test. The instrument shall be tested for scale errors at the points shown. The test shall be made by subjecting the instrument to the speeds specified to produce these readings, first with speeds increasing, then with speeds decreasing. With speeds increasing the speed shall be brought up to, but shall not exceed, the speed specified to give the desired reading, and with speeds decreasing, the speed shall be brought down to, but shall not fall below, the speed specified to give the desired reading. The errors at the test points shall not exceed the tolerances.

Indicated Speed (r.p.m.)	Tolerance (r.p.m.)	Indicated Speed (r.p.m.)	Tolerance (r.p.m.)
0	30	1,600	15
100	30	1,700	15
200	30	1,800	20
300	30	1,900	20
400	30	2,000	20
500	20	2,100	20
600	20	2,200	30
700	20	2,300	30
800	15	2,400	30
900	15	2,500	30
1,000	15	2,600	30
1,100	15	2,700	30
1,200	15	2,800	30
1,300	15	2,900	30
1,400	15	3,000	30
1,500	15		

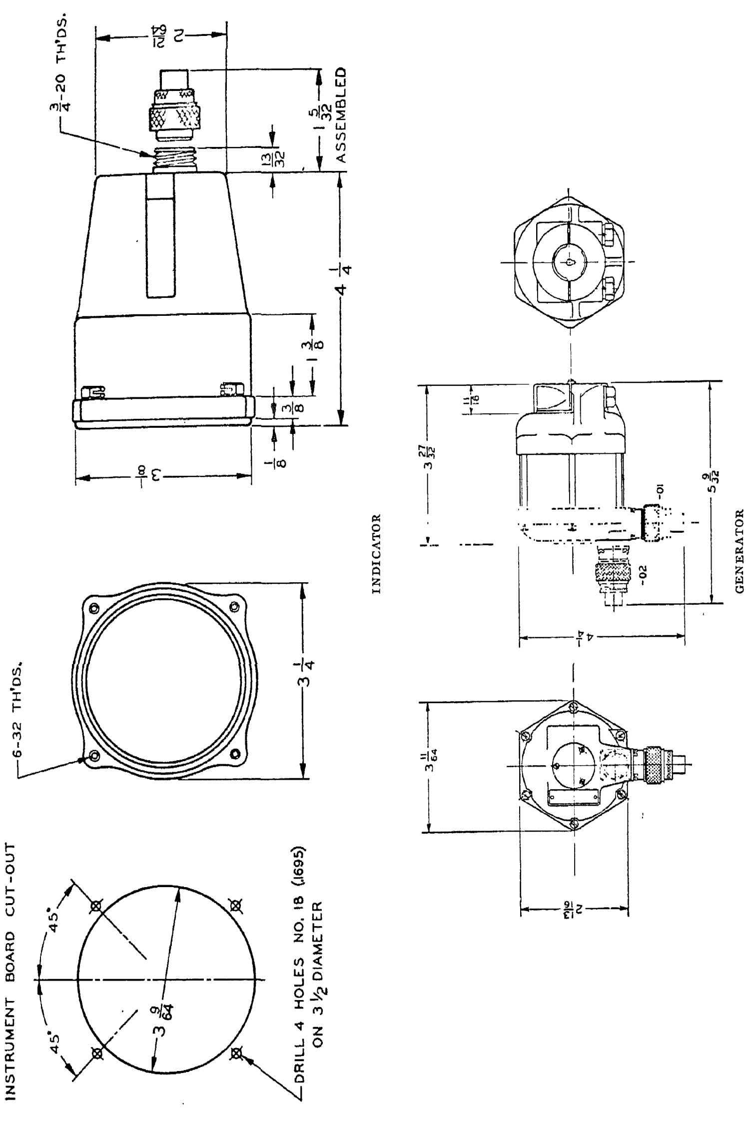
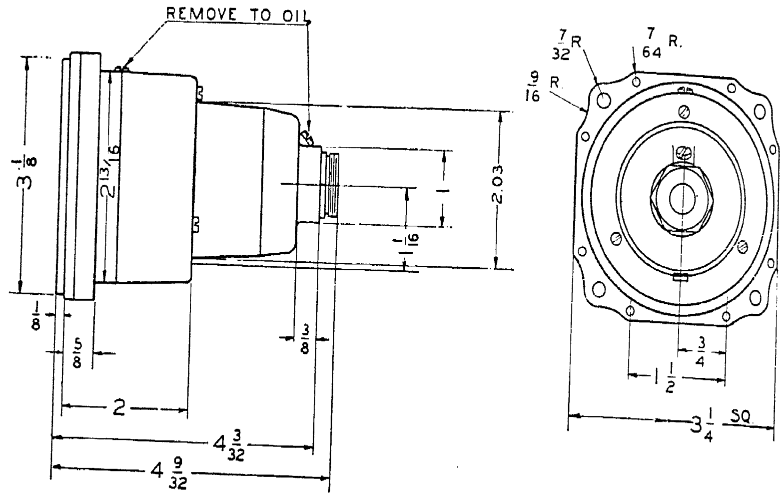
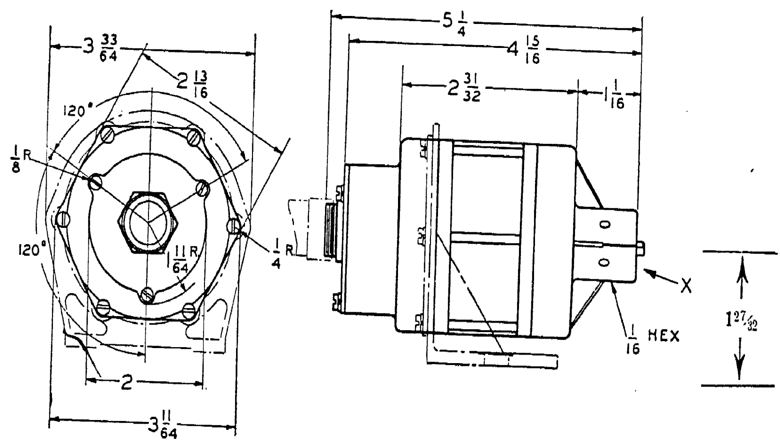


Figure 77. Installation Dimensions Kollsman Indicator and Generator
(Kollsman Instrument Division of Square D Co.)



INDICATOR



GENERATOR

Figure 78. Installation Dimensions Pioneer Indicator and Generato

(Pioneer Instrument Division of Bendix Aviation Corp.)

CHAPTER 13

MANIFOLD PRESSURE GAUGE

The pressure of the fuel vapors entering the cylinders of an engine is a definite measure of the power output of that engine. The horsepower output is a definite linear function of the manifold pressure, tachometer, and propeller pitch. Hence the manifold pressure instrument in combination with the tachometer provides the pilot with a power indicator. Every engine is rated for a definite manifold pressure at any speed in order to assure optimum operation. Operation at too high manifold pressure for even a short interval may cause serious damage or even engine failure due to overload. Operation at too low manifold pressure will result in poor fuel economy. Therefore, the manifold pressure indicator must be accurate and dependable. New airplanes cruising at higher altitudes with higher supercharged engines have brought new problems to manifold pressure measurements, not primarily in precision of measurement, but in condition under which indicating gauge must operate.

Feature of Pioneer Type

The feature of the instrument in Figure 80 is the complete isolation of the manifold vapors in a chamber containing only the aneroid diaphragm. There is no differential pressure between the inside and outside of the case or across the cover glass. Hence every part of the mechanism is available without disturbing either the pressure tight or evacuated compartments. It is covered with a dust cap equipped with a miniature air filter. Hence the jewelled cast frame mechanism is entirely protected from manifold vapors and all dust and condensed moisture.

Kollsman Cartridge Type

The vacuum cartridge type was developed to insure enduring performance under severe operating conditions. In method of

Figure 79. Pioneer Type 1918

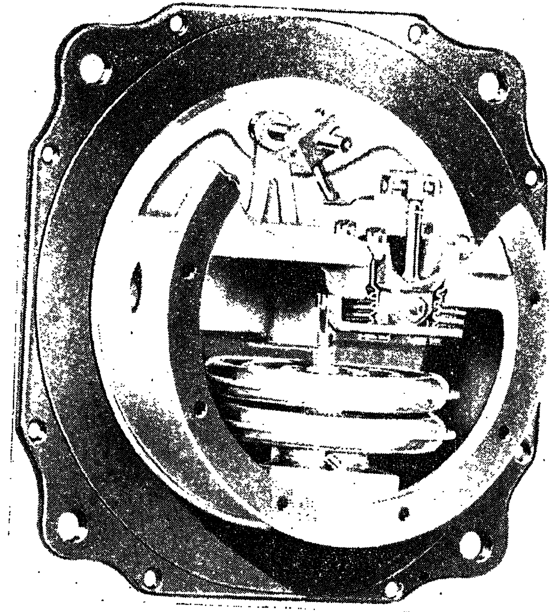


Figure 80. Cut-Away View Type 1918

(Pioneer Instrument Division of Bendix Aviation Corp.)

The darkened section of the inner rim from 36 to 50 is the warning sector.

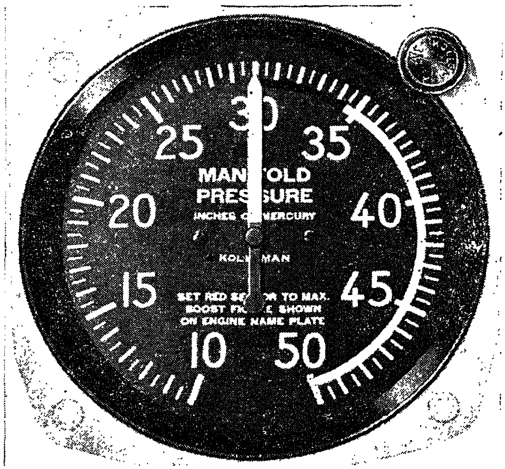


Figure 81. Kollsman Cartridge Type

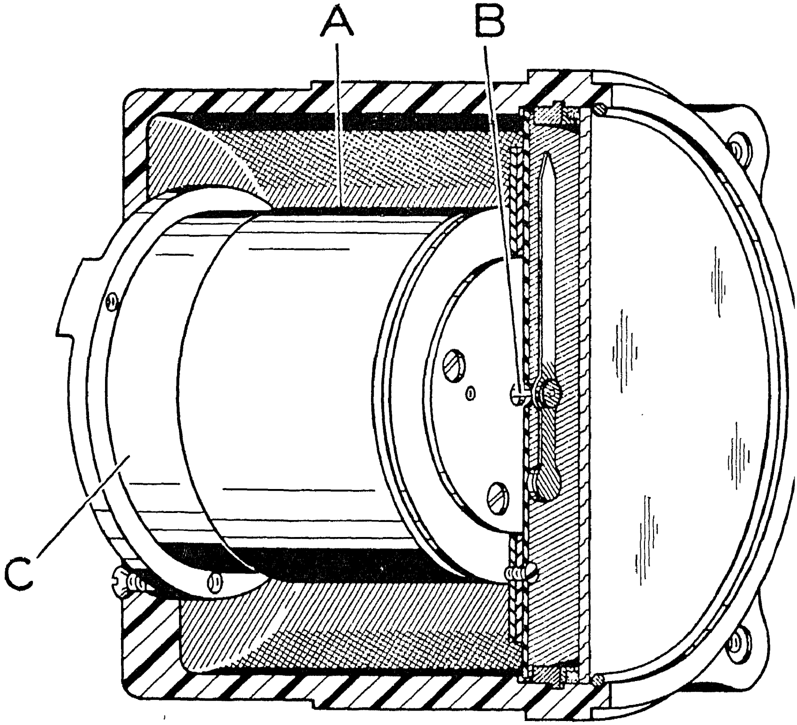


Figure 82. Schematic Drawing of Kollsman Cartridge Type
(Kollsman Instrument Division of Square D Co.)

indication it is identical with the standard type of gauge. In construction, however, it is radically different.

The mechanism of this instrument is sealed within a vacuum chamber or cartridge where it is protected against all dust and dirt and against the corrosive action of fuel vapor.

Connection from the manifold terminates at the outside of the flexible wall of the vacuum cartridge. This prevents the breathing action in the connection tubing, induced by changes of manifold pressure, from admitting fuel vapor either to the cartridge or to the case.

Operation of Kollsman Cartridge Type

The manifold pressure gauge consists of an evacuated mechanism chamber (A), one end of which is sealed with a cover containing a diaphragm section and the other end of which is sealed with a cover on which the mechanism is mounted. The mechanism enclosed in the evacuated chamber consists of a rocking-shaft assembly actuated by the movement of the diaphragm section and in turn actuating a sector that is connected to a pinion. The pinion is magnetically coupled to the hand-staff (B) which is jewel mounted. Another chamber (C) is provided in the cover containing the diaphragm section, and into this chamber a damping screw is inserted.

Operation of Kollsman Standard Manifold Pressure Gauge

The mechanism consists of an evacuated diaphragm assembly (A) and a mechanism for multiplying its deflection. A link (B) transmits the movement of the diaphragm to the rocking-shaft (C) and the sector gear (D) meshed with the gear of the hand-staff pinion (E) transmits the motion to the hand assembly. (F) is the hand.

A hairspring (G) removes the backlash in the mechanism, and a bi-metallic strip (H) compensates for temperature changes. The warning sector is adjusted by turning the shaft (I), the screw head of which is covered by a cap screw. A gear (J) on the end of this shaft meshes with the gear (K) on the sector dial assembly.

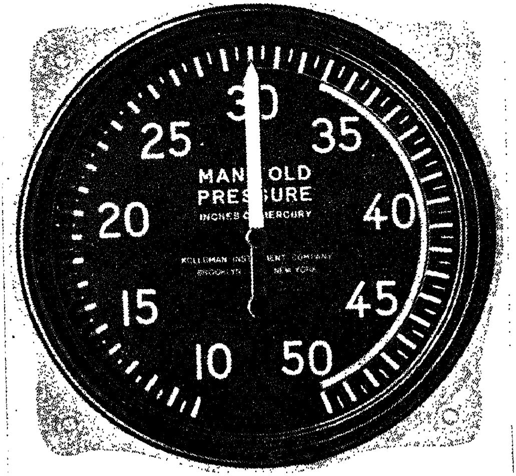


Figure 83. Kollsman Standard Type Indicator

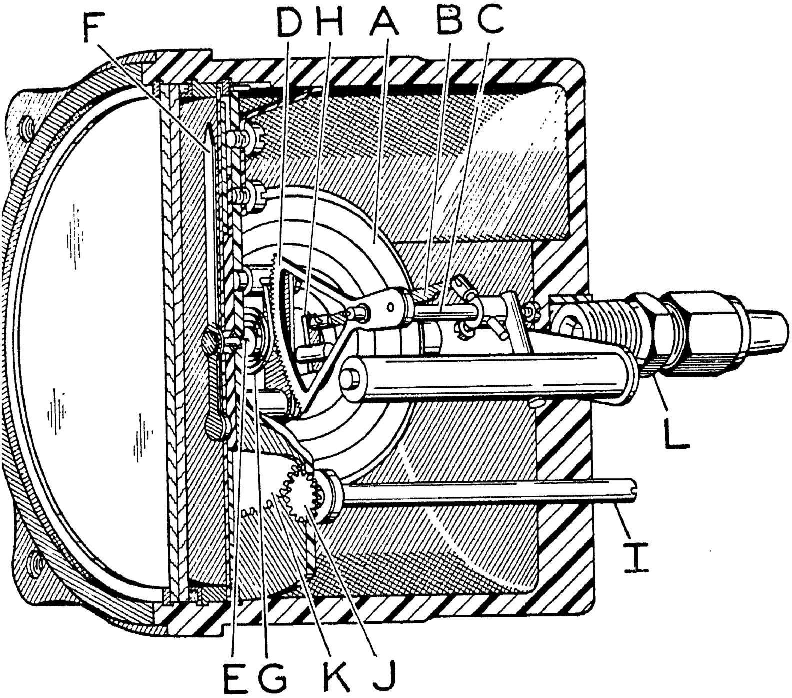


Figure 84. Cut-Away View of Kollsman Standard Type
(Kollsman Instrument Division of Square D Co.)

As the supercharging pressure increases, the diaphragm contracts. This motion is transmitted to the pointer through the rocking-shaft and hand-staff pinion. A laminated glass prevents breakage due to excessive pressure differentials between the inside and outside of the case. The small bushing found under the fitting (L) dampens pressure changes due to the breathing action in the manifold and thus prevents oscillation of the pointer.

Operation of Ashcroft Manifold Pressure Gauge

This type manifold pressure gauge consists of two opposed flexible metallic bellows, having equal effective areas. Referring to Figure 88, bellows (1) is completely evacuated and bellows (2) is connected to instrument outlet by tubing (19). Pressure

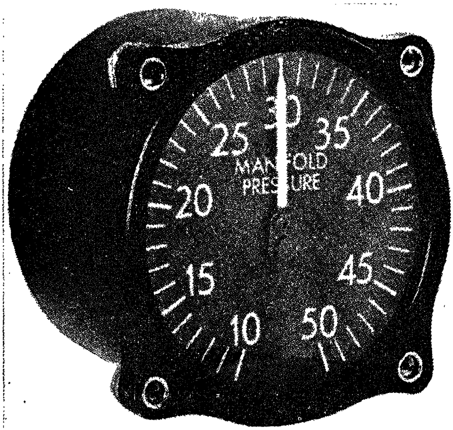


Figure 85. Ashcroft Manifold Pressure Gauge Type 6742

bellows head (4) and vacuum bellows head (9) are rigidly attached to instrument frame (10). Movable pressure bellows head (5) and movable bellows head (18) are rigidly connected to each other by spacer sleeve (6). A helical tension spring (3) is wholly enclosed in pressure bellows (2) and axially fastened to stationary head (4) and movable head (5). Since bellows (1) is completely evacuated, helical spring (3) will always be

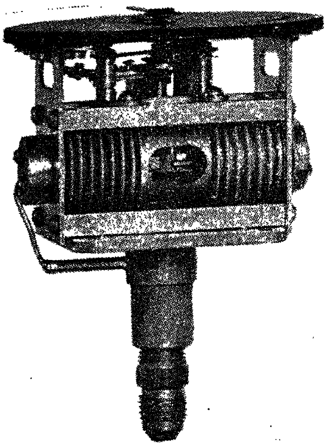


Figure 86. Internal Mechanism with Case Removed

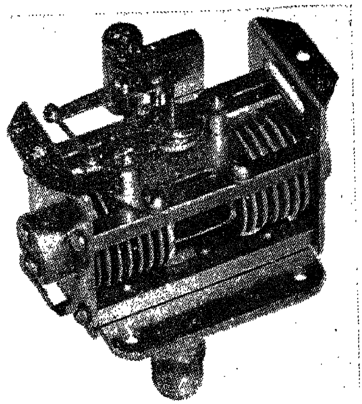


Figure 87. Internal Mechanism with Dial and Pointer Removed

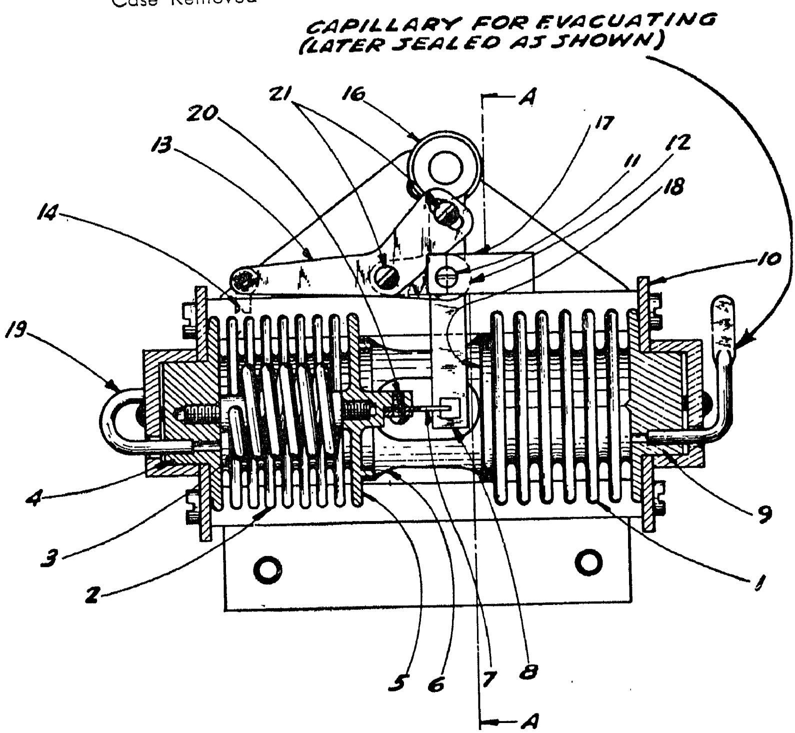


Figure 88. Cross-Section Through Longitudinal Axis of the Bellows

under tension when pressure in bellow (2) is other than zero absolute. Increasing absolute pressure consequently causes the bellows heads (5) and (18) and connecting spacer sleeve (6) to move to the right. Since the two opposed bellows have equal effective areas, the effect of changes in external barometric pressure is balanced out and deflection of bellows is consequently independent of external barometric pressure and depends entirely on changes in absolute pressure in bellows (2).

Deflection of opposed bellows is transmitted from center of pressure bellows head (5) to rocker-shaft arm (8) by flexible strip (7). Angular displacement of rocker-shaft arm (13) is transmitted through link (14), shown partially, to conventional geared sector and pinion movement.

Rocker-shaft (12) is carried in two point pivots (11) which are screwed into rocker-shaft mounting bracket (17) and securely held by self-locking slots. Counterweight (16) is substantially equal to the effective mass of the bellows assembly, thus balancing the unit both for vibration and positional error.

Test Apparatus

This is a mercury-filled manometer used for accurately calibrating manifold pressure gauges. It is designed for shop or laboratory use and is adapted to any application where pressure in inches of mercury is desired.

This type consists of a uniform glass tube connected integrally with a large reservoir containing mercury, a double metal scale for measuring pressures both above and below normal, a supporting stand and the necessary connecting tubing. The reservoir, not visible, is in a protective casing behind the scale.

The double or twin scale provides a means for measuring pressures in a range above and below atmospheric pressure or from 10″ to 50″ of mercury. The scales are movable so that they may be "zero" adjusted to the existing barometric pressure at time of test. Lower part of each scale is marked off in millimeters of mercury with the range of atmospheric pressure.

Both the reservoir end and the upper end of the manometer have attached rubber tubing for connection to the pressure or suction supply and the instrument being tested. Only one end is

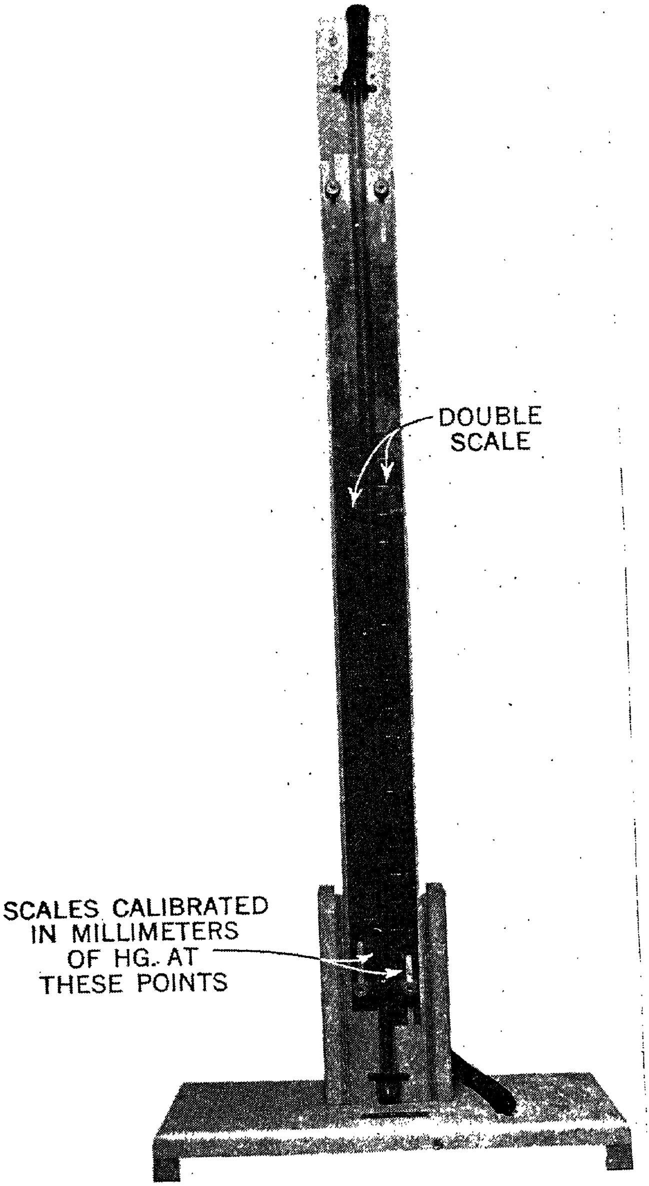


Figure 89. Pioneer Test Manometer for Manifold Pressure Gauge
(Pioneer Instrument Division of Bendix Aviation Corp.)

used at a time, the other remaining open to the atmosphere. The pressure or suction supply may be obtained from any form of hand- or motor-driven pump. If a motor-operated pump is used, an air reservoir is desirable. A recommended arrangement is a tank (a 5-gallon bottle) placed between the pump and testing equipment. The reservoir dampens out any fluctuation of pressure in the supply system and permits a more even change of pressure when the inlet valve is open. A simple valving arrangement should also be provided in each line. It is possible to test several instruments at the same time by connecting each to a separate outlet from the main pressure line.

Directions for Tests

The first operation is to "zero" the scales corresponding to the existing barometric pressure at the time of making the tests. This pressure may be obtained from a barometer or from the Weather Bureau in the vicinity. For calibrating the manifold pressure gauge in the range of pressures above barometric to 50″ of mercury, the instrument is connected by the tubing to the reservoir end of the manometer. The instrument should indicate the same "zero" barometric pressure as the manometer. Pressure is then applied in amount corresponding to each inch of mercury on the scale and the instrument checked at these pressures both up and down the scale. The manometer and indicator should be tapped lightly before each reading to eliminate any friction errors.

The same procedure is repeated for pressures below barometric down to 10″ of mercury. In this case the connection is made to the upper end of the manometer and suction is applied to the system.

Test Specifications

The following test specifications pertain to Pioneer Type 1918 and for all other types and makes the instrument manufacturer's testing manuals should be consulted.

Scale Error Test. The instrument shall be tested for scale error by subjecting it successively to the pressures listed.

The pressures shall be reduced or increased at the rate of approximately 2″ (5 cms.) Hg pressure per minute. A rest of at least one minute shall follow the change in pressure before the indicator is read. The errors at the test points shall not exceed the tolerances specified in the following table. The difference between up and down readings shall not exceed 0.3″ (.75 cms.) Hg.

Pressure In. Hg Abs.	Tolerance	Pressure Cms. Hg Abs.	Tolerance
10	±0.40	30	±1.00
15	.40	40	1.00
20	.30	50	0.75
25	.20	60	.75
30	.20	70	.65
35	.20	76	.65
40	.30	80	.65
45	.40	90	.75
50	.40	100	.75
		110	1.00
		120	1.00

Leak Test. A pressure, sufficient to produce full scale deflection of the pointer in the positive direction, shall be applied to the pressure connection of the instrument. The connecting tube shall then be pinched off at a point within 2″ of the pressure connection. During a period of one minute the pointer shall not change its position more than 0.1″ (.25 cms.) Hg.

Damping Test. A pressure, sufficient to produce full scale deflection of the pointer in the positive direction, shall be applied to the pressure connection of the instrument. The connection to the fitting shall then be suddenly broken at the point of attachment, and the time noted for the pointer to come to a reading of 32″ (80 cms.) Hg. The time required for the pointer to attain this reading shall be from one to two seconds.

Installation (Pioneer Type 1918)

The manifold pressure gauge is usually used in conjunction with the tachometer and should be mounted near that instrument.

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35	.20	76	.65
40	.30	80	.65
45	.40	90	.75
50	.40	100	.75
		110	1.00
		120	1.00

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Installation (Pioneer Type 1918)

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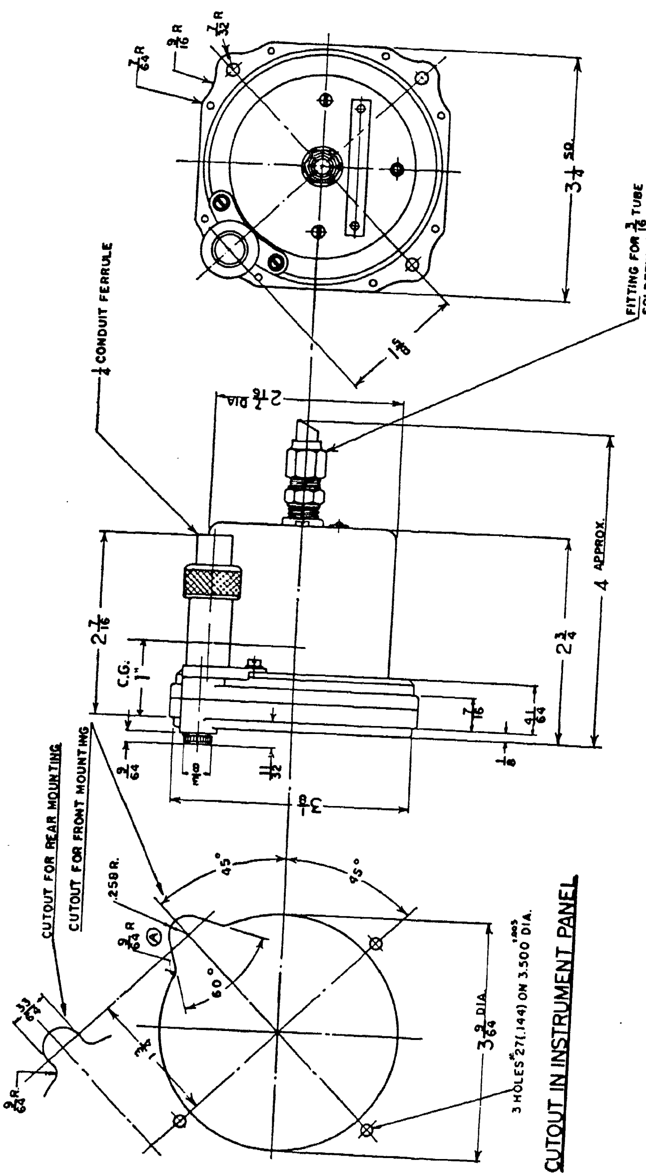


Figure 90. Pioneer Type 1918 Installation Dimensions
(Pioneer Instrument Division of Bendix Aviation Corp.)

The vaporproof manifold pressure gauge has an internal damping device inside the case. The pressure outlet fitting merely serves the one function of pressure connection. The other pressure connection is made to the pressure fitting provided in the intake manifold of the engine. This connection should not be made at the bottom of the manifold, because large quantities of condensate would get into the gauge line. The minimum size recommended tubing for the above connection is 3/16″. If, for any reason, the damping constriction in the gauge should become clogged, the instrument must be removed and cleaned but only by a qualified instrument repairman.

(For ringlighted instrument only.) Electrical connections are made to a small 2-wire disconnect plug on the rear of the instrument case. The plug is fitted with a swedged fitting for a ¼″ conduit. The insulation on the 2-wire cable should be removed from the wires for receptacles of the female plug assembly. After unscrewing the ferrule and nut and sliding them on to the 2-wire cable in the proper order, the conduit should be swedged to the ferrule. After the female plug assembly is pulled out of its housing, the two tinned ringlight wires can be inserted into the two receptacles of the plug and tightened with the two screws provided. The plug should now be pushed back into its housing and the shielding nut screwed down on top of the ferrule. The male ringlight plug assembly contains the resistor that limits the current to the 3-volt lamp to 0.2 amperes when 12 volts are applied to the plug.

Prior to installation, the warning sectors (see Figure 79) under the dial must be set at the desired settings shown on the engine nameplate. This is done by unscrewing the eight bezel ring screws on the front of the instrument and lifting off the bezel assembly. (The bezel screw seal must be broken to do this.) In order to remove the dial the pointer must be lifted off (with a pointer lifter) and the two dial screws taken out. Under the dial is the warning sector assembly. The sectors are held in position by friction and can be rotated to the desired position. After they are set the dial and dial screws are put back on and the pointer reset so that it reads the prevailing atmospheric pressure when the instrument is tapped. The pointer hub can

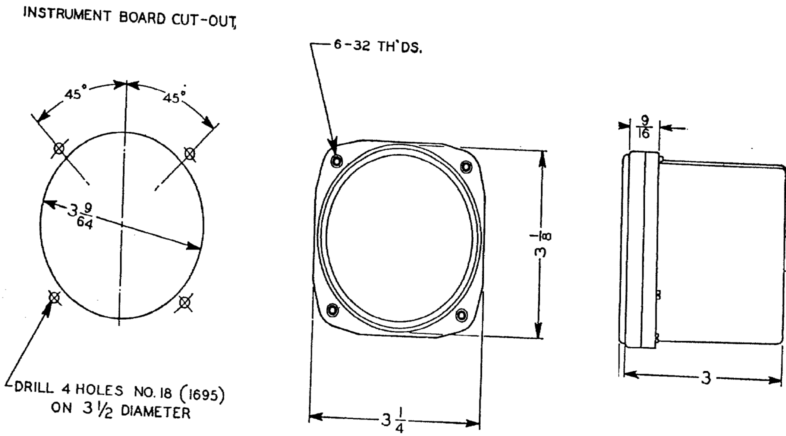


Figure 91. Kollsman (Cartridge Type) Installation Dimensions
(Kollsman Instrument Division of Square D Co.)

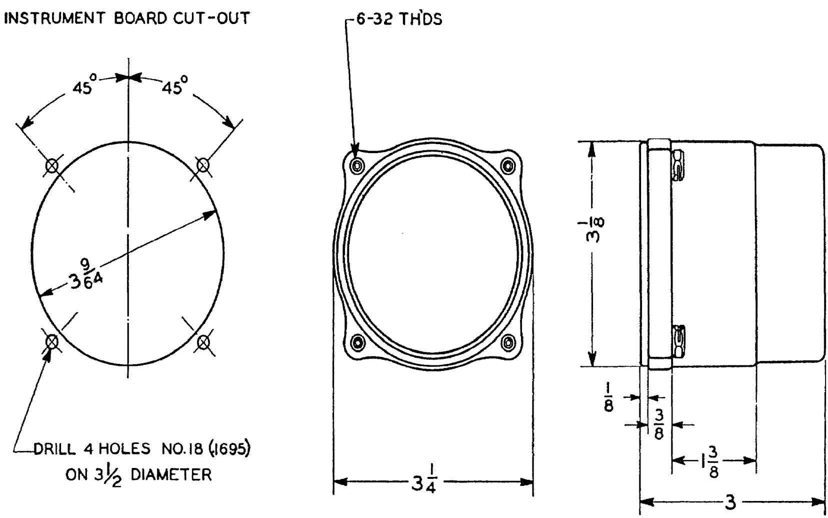


Figure 92. Kollsman Standard Type Installation Dimensions
(Kollsman Instrument Division of Square D Co.)

then be pushed down on the staff with an eraser-tipped pencil. The bezel ring assembly should then be placed face down on the bench and the rings and gaskets properly adjusted. If the instrument is ringlighted, the light ring should be held in place by a Pioneer dummy lamp screwed in the light well during the bezel assembly operations. The instrument should then be placed face down on the bezel assembly in the proper position. The bezel and the instrument should now be held together and turned face up on the bench. If the above operations are completed carefully, no further adjustment of the rings or gaskets should be necessary. The eight bezel screws should then be tightened down uniformly. The operations described in the above paragraph should be done in the instrument shop.

For maximum performance and life it is recommended that this instrument be mounted on a panel suitably damped from vibration. The maximum amplitude (total movement) of vibration should not exceed 0.008″. When the instrument is installed on a vibration absorbing panel, a suitable length of nonmagnetic flexible tubing (approximately 10″) should be connected between the instrument and the connecting tubing.

Maintenance

In the event of unsatisfactory operation of the manifold pressure gauge the following points should be checked before the instrument is removed from the airplane.

(a) Leaks in connecting line or case: Apply suction to the engine end of the connecting line using a hand vacuum pump and while watching the hand of the instrument, shut off the vacuum when the hand reaches the lowest point on the scale. If the hand returns to its zero position at a rate greater than 0.4″ (10 millimeters) of mercury per minute there is a leak in the connecting tube or the instrument case.

(b) To check for a leak in the instrument case, remove the connecting tube from the back of the case and apply suction to the instrument until the pointer again reaches the lowest point on the dial. If the rate of motion of the pointer is now within the limits specified above when the vacuum is shut off, the case

Figure 93. Flight Engineer at his Post in Pan American's Boeing 314
(Pan American Airways)

may be considered airtight and the leak located in the connection tube.

(c) Leaks in the line may be eliminated by tightening all connections and replacing porous tubing. If the leak is in the case the instrument should be removed for repairs.

CLOGGED CONNECTING LINE. Disconr
line at both ends and blow it out with
erate pressure.

TROUBLE CHART

TROUBLE	CAUSE
(a) No indication or sluggish response.	Foreign matter in connecting line. Damping restriction in instrument clogged.
(b) Pointer far off correct reading. Pointer travel limited.	Broken diaphragm strap. Broken pivot. Loose pointer.
(c) Sticking or excess friction.	Bent or broken pivot. Cracked jewel. Foreign matter in mechanism. Insufficient end play of rocking shaft.
(d) Excessive oscillation.	Insufficient hairspring tension. Excessive end play of rocking shaft.
(e) Erratic or low readings.	Leaks in connecting line. Leak in the instrument.

CHAPTER 14

PIONEER AUTOSYN

The Autosyn system satisfies one of the basic requirements of multi-motor airplane design by making possible accurate remote indication of the functions of the aircraft and its engine through efficient electric transmission. A combination of simple transmitting and indicating elements, which may be widely separated, comprise the basic units of the Autosyn system.

Autosyn Operation Principles

Autosyn basically applies the principle of self-synchronous motor operation. The prime function of self-synchronous motors is the duplication of motion of one motor in another. These two motors, which may be remotely separated, operate in exact synchronism, the rotor of one motor following the least motion of the rotor of the other motor. Simple electrical wiring between these two units eliminates all mechanical connections and tubing.

For an operating source of power, alternating current is used. The Autosyn system can be designed to operate under any combination in a wide range of voltage and frequency. If alternating current is not available, or is not a part of the aircraft's power supply, a separate generator may be included as part of the accessory equipment.

In aircraft Autosyn the motors are used only to duplicate the extent or position of an instrument function at some remote point. Although rarely called upon to operate in continuous rotation, the units are known as "motors" for the purpose of explanation. Autosyn within itself functions primarily as a phase-indicating device capable of continuous operation for hundreds of hours in service without attention.

Figure 94. Autosyn Dual Manifold Indicator

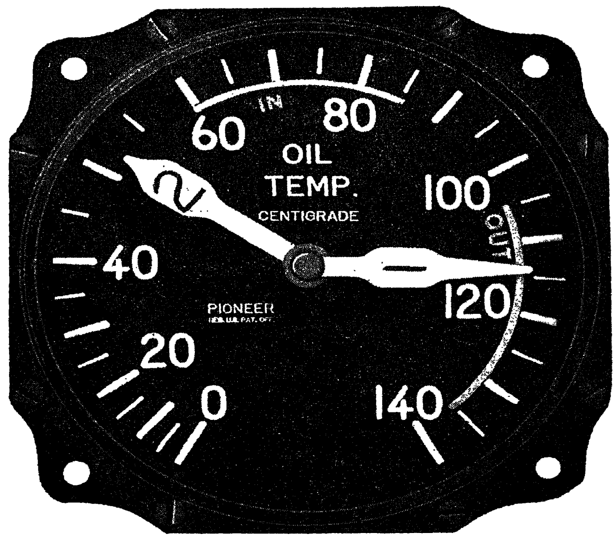


Figure 95. Autosyn Dual Oil Temperature Indicator

(Pioneer Instrument Division of Bendix Aviation Corp.)

The Autosyn system consists essentially of a transmitting unit located near the source of measurement, and a receiving or indicating unit mounted on the instrument board. Both units contain as an integral part a small Autosyn "motor." The transmitting "motor" is attached directly to the sensitive instrument element, the whole assembly being located conveniently near the source of measurement. Connected to the indicating "motor" on the instrument board a pointer establishes a position in synchronism with the transmitting unit.

The sensitive element of the transmitter is connected mechanically to the source of measurement. The element, for example, may be an oil pressure Bourdon tube or a fuel pressure diaphragm. The sensitive element rotates the rotor of the transmitting "motor" in the same manner as it would a pointer on a dial.

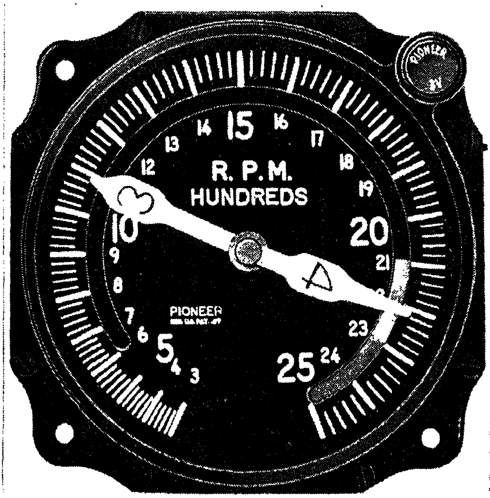


Figure 96. Autosyn Dual Tachometer Indicator
(Pioneer Instrument Division of Bendix Aviation Corp.)

To the indicator on the instrument board, simple wiring carries electrically the position of the transmitting rotor to the rotor of the indicating motor. The indicating motor operates directly a pointer on a dial which is calibrated with a scale cor-

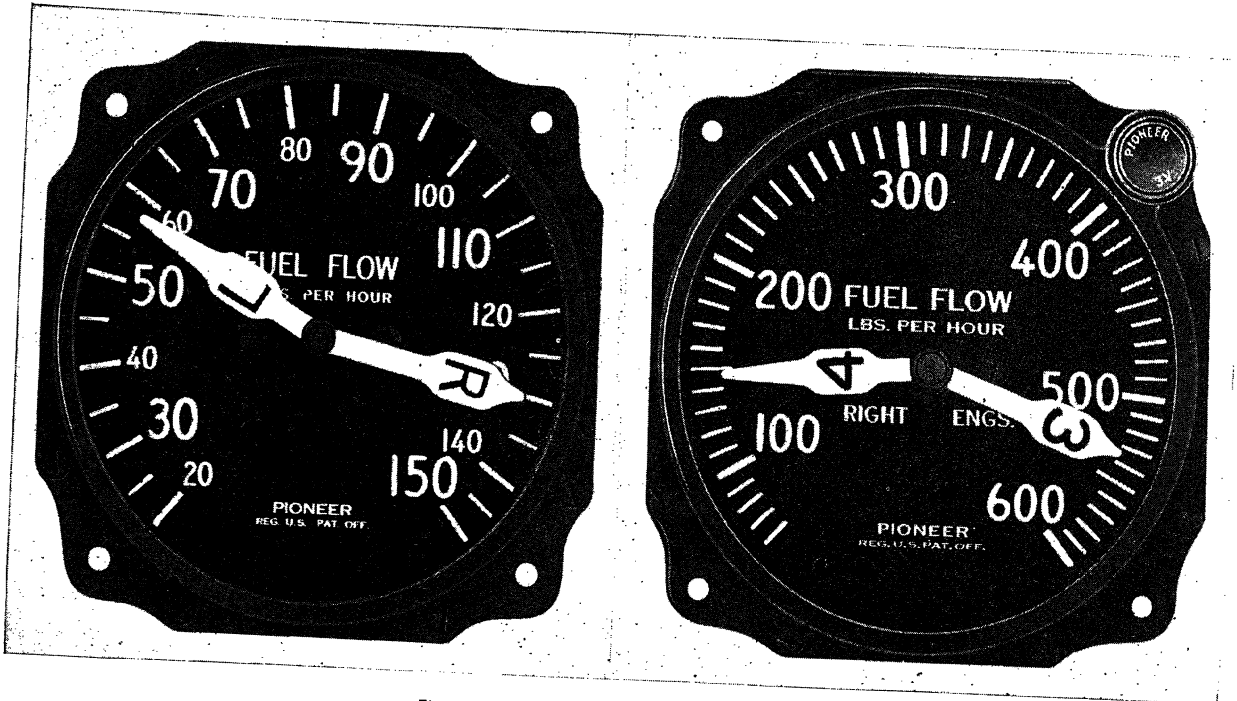


Figure 97. Autosyn Dual Fuel Flow Indicator
(Pioneer Instrument Division of Bendix Aviation Corp.)

responding to the function measured. The result is that any movement of the sensitive element in the transmitter is immediately registered by a corresponding movement of a pointer on the indicating dial. To accomplish the accuracy so inherently a part of Autosyn, the low weight rotors are carried on high-grade ball bearings which practically eliminate friction and permit operation of the system by a very low torque.

The instrument board indicator consists simply of Autosyn "motors" with pointers attached to their rotor shafts. An important development, particularly adaptable to Autosyn, is the dual indication of two functions on a single dial. This is possible with the tandem indicator which contains two motors, the shaft of the rear motor extending through the hollow shaft of the front motor. By this means, the indications of right- and left-hand engines of a bi-motor, or each pair of outboard engines of a four-motor ship, are given by two concentric pointers on a single dial. Similarly, the fuel quantity of two tanks may be simultaneously indicated on one dial. The pointers are designed to readily identify the source of the measurement.

A further development is the use of a selector switch in conjunction with multiple scale indicator, so that a single indicator might be used for several functions, such as oil, fuel and manifold pressure and oil temperature. Several scales, properly identified, are incorporated on a standard size dial. A two-pointer dual or tandem indicator, together with a four-scale dial and selector switch, makes possible a combination of eight instruments in one. The principal advantage of this arrangement lies with the greater ease of reading by the pilot and the conservation of instrument board space. Where it is necessary to have continuous indication of all instrument functions, such as in the flight engineer's compartment, the indications can be duplicated by individual indicators.

Autosyn Energy Supply

Single phase alternating current is used for supplying the energy to the Autosyn system. While the system can be designed to operate under any combination in a wide range of

voltage and frequency, the standard is either 32 vc
or 110 volts-800 cycle. There are several possible
this alternating current supply.

Due to its many advantages in aircraft application, alter
ing current is certain to become an addition to the
system by supplementing the direct current supply f

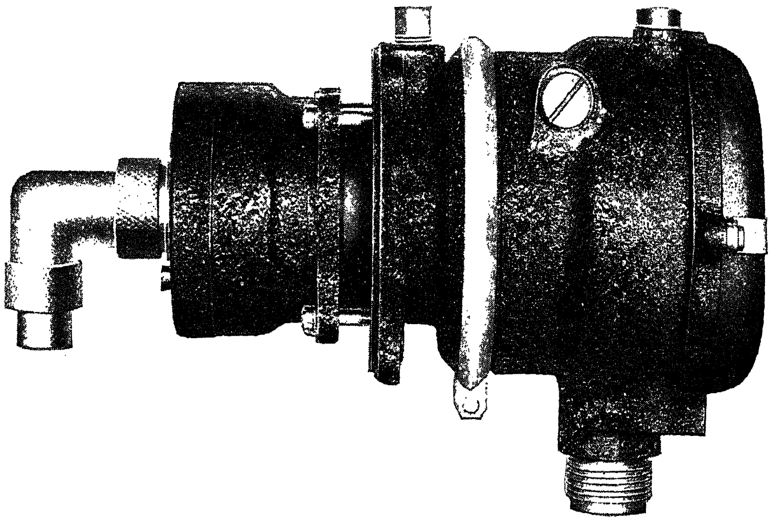


Figure 98. Pioneer Autosyn Tachometer Transmitter
(Pioneer Instrument Division of Bendix Aviation Corp.)

functions which can be operated more efficiently by alternating current. This becomes a natural development with the installation of the separate power unit which can also operate an alternating current generator. An alternating current supply, especially high frequency, means greater efficiency and less weight for operation of such components as motors for starters and retractable landing gear, aircraft radio, cabin lighting and Argon instrument panel illumination, landing and navigation lights. Autosyn instruments then truly fit into the scheme of modern aircraft development.

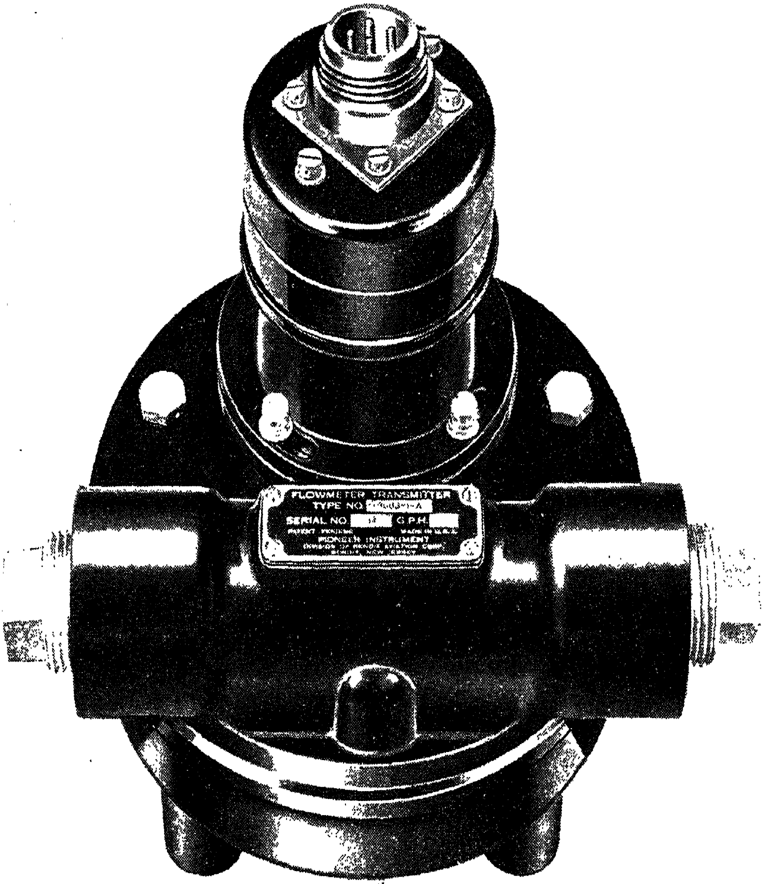


Figure 99. Pioneer Autosyn Fuel Flowmeter
(Pioneer Instrument Division of Bendix Aviation Corp.)

In general then, there are several possible sources for the alternating current power supply, and these can be summed up as follows:

(a) Where a separate power unit for operating accessories is part of the aircraft equipment, an alternating current generator can be included.

(b) Engine-driven alternators may be installed and operated from the spare tachometer drive connection of the engine. The diagrammatic illustrations on the last pages incorporate engine-driven alternators. This system is recommended only where a separate power plant is not available. Each alternator may supply power for the Autosyn instruments associated with the particular engine to which they are connected, or in the case of multi-motor ships, a system of two alternators, each capable of carrying the full Autosyn load, might be advisable. The remaining engines are then left free to carry other accessories that may be necessary, such as the direct current supply system.

(c) A dynamotor or converter, operated by the direct current system, may be used.

(d) An alternating current system, installed for operation of radio or any other accessory, may also be used to operate Autosyn.

Instrument Applications

Autosyn transmission applied to the airplane may be adapted to the remote electrical indications of almost any desired instrument function. Some of these various instrument elements are briefly described in the following paragraphs.

Engine Gauges. For engine conditions of pressure and temperature, standard instrument elements such as Bourdon tubes and diaphragms, are mounted as part of the transmitting Autosyns. For multi-motor airplanes, dual indicators in conjunction with selector switches and warning lights, are desirable. These give the pilot all the engine information necessary, saving confusion and instrument board space.

Tachometers. A conventional type mechanical tachometer element is connected directly to the transmitting Autosyn. The value of a short flexible cable is apparent in this case.

Fuel Flow Indicators. The transmitting element, located in the fuel supply line to each engine, operates a weight per unit time indicator. Autosyn has made possible accurate fuel flow indication.

Fuel Quantity Indicators. Standard fuel level elements of an improved design, principally of the float type, are incorporated with Autosyn transmission.

Radio. Where radio equipment is installed in the rear of a ship, tuning can be accomplished by electric motor drive controlled from the cockpit. Autosyns can be used to transmit the position of the condenser being tuned and also are used to accurately indicate radio loop bearing indications on a dial on the instrument board.

Advantages of Autosyn System

(a) Eliminates long tubing and driving shafts which are replaced by electric multi-wire conductors.

(b) Eliminates errors in oil pressure indication due to oil congealing in the capillary under low temperature conditions.

(c) Eliminates fuel and oil lines from the pilot's compartment, reducing the fire hazard and engine failure possibilities.

(d) Conserves instrument board space on the panel by using dual and multiple scale indication which results in greater ease of reading by the pilot.

(e) Service requirements are reduced to a minimum due to the simplicity and accessibility to the equipment and the elimination of long tubing which is the principal source of trouble.

(f) Sufficient spare conductors can be included in each cable to allow quick substitution of any broken conductor or addition of new instruments.

(g) The removal of wings is facilitated by conveniently locating a terminal box or multiple plug near the junction.

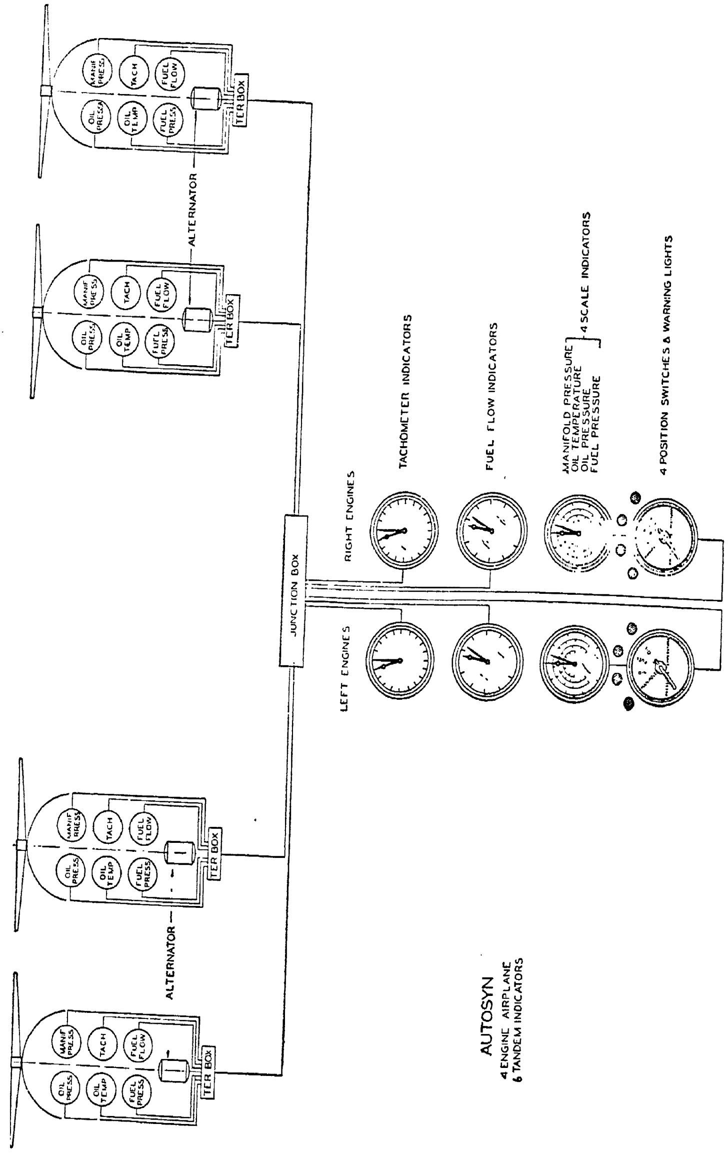


Figure 100. Pioneer Autosyn Four-Engine Airplane
(Pioneer Instrument Division of Bendix Aviation Corp.)

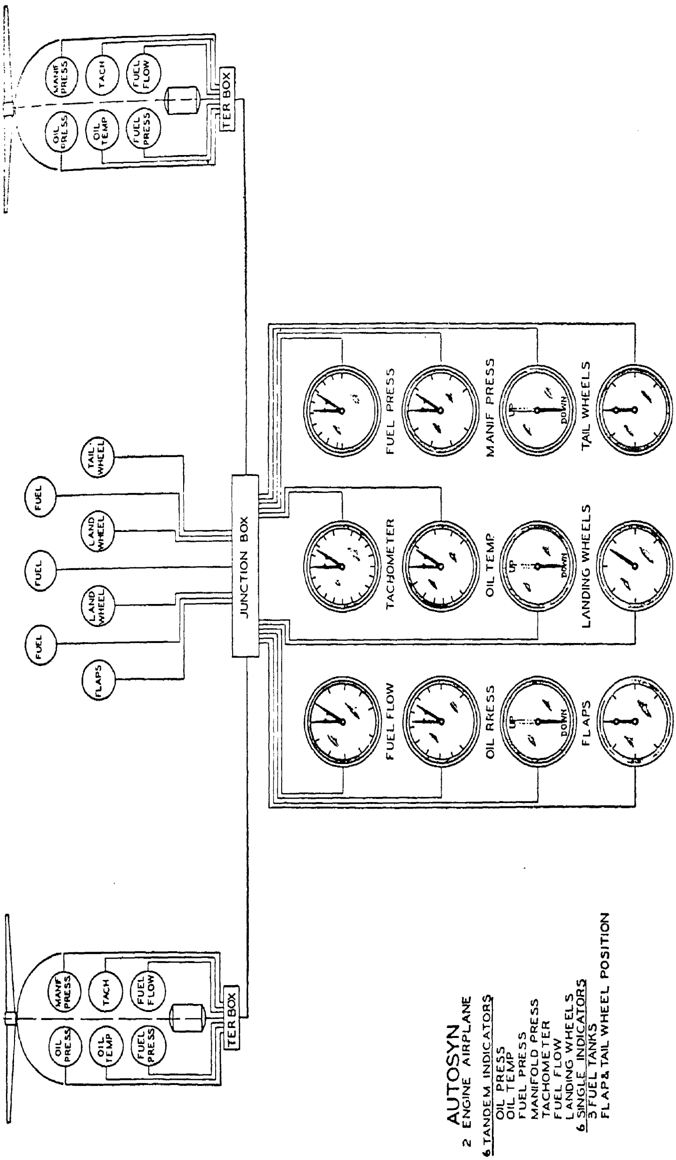
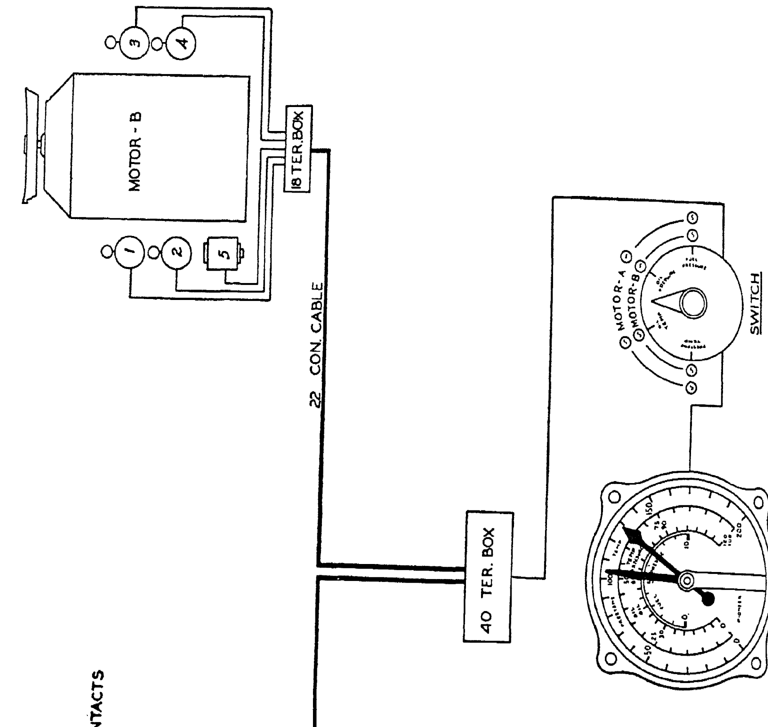


Figure 101. Pioneer Autosyn Two-Engine Airplane
(Pioneer Instrument Division of Bendix Aviation Corp.)



CODE	QUANTITIES AUX.	TRANS.	IND.
1 OIL PRESSURE		2	2
2 OIL TEMPERATURE		2	2
3 PRESTONE TEMP.		2	2
4 FUEL PRESSURE		2	2
5 ALTERNATOR	2		
18 TERMINAL BOXES	2		
40 TERMINAL BOX	1		

Figure 102. Two Motor Ship Wiring Diagram

(h) Standardization: Both transmitting and indicating motor elements are very nearly identical, the case being the principal difference. Instrument board indicators are fully interchangeable by change of dial.

(i) Alternating current, which is a required part of the system, can be used for ultra-violet light instrument panel illumination. While the radium paint is extremely sensitive to ultra-violet, the visible "white light" cockpit illumination is kept at a minimum. This results in increased piloting efficiency, and in military aviation operation adds a special feature of safety.

It is recommended that the transmitting element be located as close to the source of measurement as convenient so as to reduce as much as possible the length and weight of such mechanical connections as tachometer shafts and tubing. In each engine nacelle, where there are several transmitters, these may be grouped together in a common junction box where they are easily accessible without causing interference. A shock-proof mount can be used but it is not absolutely necessary as Autosyn instruments are in themselves inherently very rugged.

Five similar terminal connections are provided on the rear of both the transmitting and indicating units. Three designated, 1, 2, and 3 come from the stator and should be connected to the corresponding terminals of the other unit. Terminals marked "A" and "G" are from the rotor and are the power wires carrying the alternating current. The "A" and "G" terminals of all the transmitting and indicating motors in the system are connected in parallel to the alternating current supply. A recommended method is the use of a single wire between all "A" terminals, with the "G" terminals grounded to the structure.

Either individual wires or multi-conductor cables can be used. Where the system comprises several instruments, the advantages of a cable can be seen. Wires of the smallest practical size, from a mechanical standpoint, can be used. Now for example assuming engine installations of fuel, oil and manifold pressure, oil temperature, fuel flow and tachometer Autosyns in a bi-motor, there would be required eighteen conductors between the cock-

INSTALLATION AND WIRING

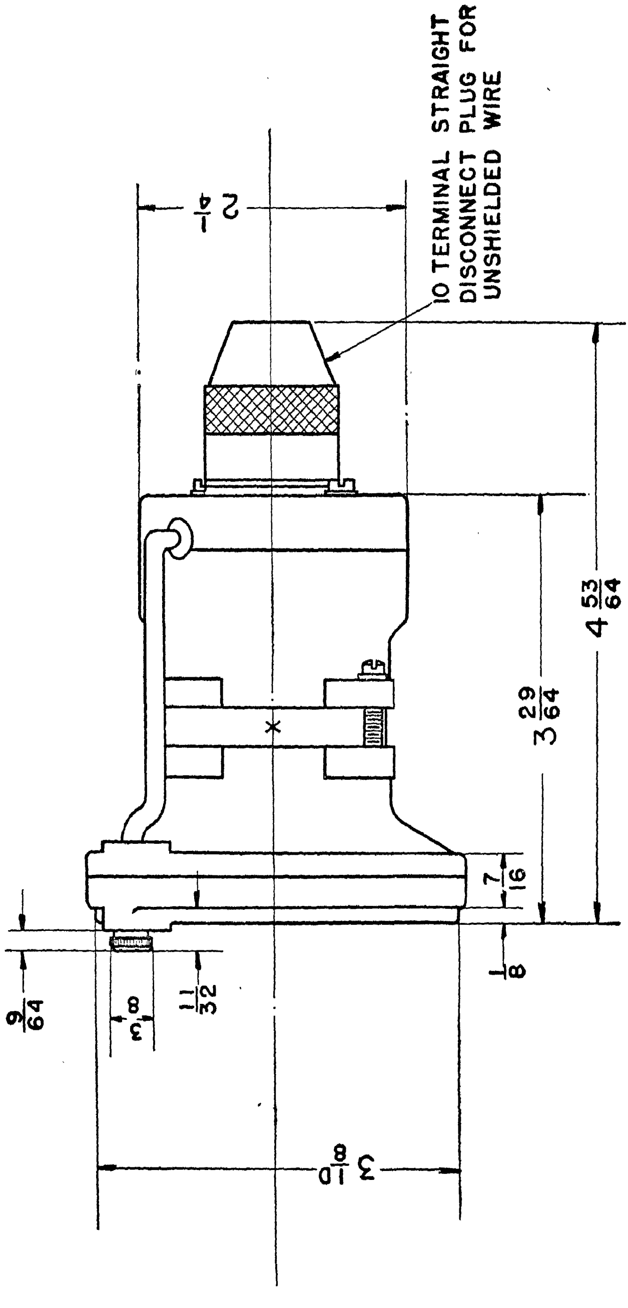


Fig Mounting Dimen ons
AUTOSYN INDIC TOR

pit and each nacelle. The two power terminals of each transmitter and indicator are connected directly to the alternating current power supply of the airplane. A recommended installation would be a cable of twenty-two conductors which would have an overall diameter of about 3/8″. The spare conductors could take care of a possible added Autosyn instrument and

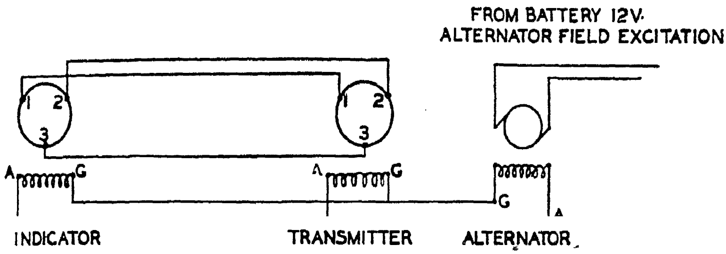


Figure 104. Autosyn System—Wiring Diagram

could be used where replacement in service is necessary: Such a cable, permanently installed, should last the life of the ship without attention or replacement.

Installation

Because of the severe vibration conditions present in engine nacelles, transmitter units are installed on vibration-absorbing mountings. This is done by placing the several transmitters of each engine together in a group and by mounting them on a panel which is suspended on rubber shock absorbers.

It is recommended that the maximum amplitude of motion of this mount should not exceed 0.010″ through the normal engine operating range.

Similarly, the indicators are usually mounted on panels, suitably damped from vibration and shock loads. The indicators should never be subjected to vibrations of total amplitude greater than 0.010″.

With the transmitter units shock-mounted, pressure and mechanical connections to these units should be made by means of a hose or flexible metallic tubing. These connections should

not be supported by brackets or clamps closer than approximately 14″ to the unit, in order to permit freedom of motion of the shock-mount. However, special attention should be given to proper support of temperature bulb capillaries and tachometer shafts throughout the remainder of their length. Kinks must be avoided and bends should be of long, gradual radius, with frequently spaced support clamps, preferably having a rubber shock-absorbing grommet. All connections should, of course, be tight and pressure, fuel and oil lines be leakproof. This may be facilitated by the use of suitable sealing compound, but such compounds must be used sparingly in order to prevent any possibility of clogging the lines or damping restrictions in the instruments. In the case of fuel pressure gauges it is recommended that a constriction be supplied at the carburetor end of the line, so that a line failure will not cause a serious leak. All transmitters of the pressure type are equipped with 1/8″ FPT fittings, and 3/16″ lines should be used for the connections.

Autosyn General Service

Before attempting any repairs or replacement of Autosyn instruments, it should be definitely established that the wiring and all external connections, including the plug contacts, are correct and in good condition, these being the most common sources of difficulty. The continuity of wiring should be carefully checked, using a simple battery and bell-ringing or test lamp rig. The continuity within the instrument itself can be checked with the aid of an ohmmeter. The DC resistance between the rotor terminals should be between 40 and 50 ohms, and the DC resistance between any two of the stator leads on one motor should likewise be between 40 and 50 ohms.

Autosyns will operate, though not always correctly, even if the voltage and frequency are far outside limits, or if one or more lead wires are broken or even if no power at all is supplied to one of the two motors that are connected together.

On pages 145 and 146 is shown an Autosyn aircraft wiring trouble table which lists the nature of the trouble, its probable cause, and the remedy.

Autosyn Aircraft Wiring Trouble Table

(Only for installations employing grounded secondary)

Trouble	Probable Cause	Remedy
(a) Indicator pointer locked at top dead center of dial (transmitter rotor locked 180° from corresponding position).	#1 disconnect plug terminal, or "G" terminal plate number, of *transmitter* not connected to power supply.	Check and fix *transmitter* ground connection.
(b) Indicator pointer locked at bottom center of dial (transmitter rotor locked 180° from corresponding position).	#1 disconnect plug terminal, or "G" terminal plate number, of *indicator* not connected to power supply.	Check and fix *indicator* ground connection.
(c) Indicator has erratic movement through an arc of approximately 40° as transmitter is actuated.	#2 disconnect plug terminal, or "A" terminal plate number, of transmitter or indicator not connected to power supply (AF or AB, or #2 or #4 on dual indicators).	Check and fix power (hot) lead on either transmitter or indicator.
(d) Indicator pointer drifts in an arc of 120° as transmitter is actuated.	#3 or #5 disconnect plug terminal, #1 or #3 terminal plate numbers, not connected between transmitter and indicator. (#3 or #5, #8 or #10 on dual indicator.)	Check and fix open stator lead.
(e) Indicator pointer locked at top center of dial and transmitter rotor locked in corresponding position and/or Primary circuit fuse blown (almost simultaneously).	#1 and #2 disconnect plug terminals, "A" and "G" terminal plate numbers, reversed on transmitter or indicator. (AF or AB and G; #1 and #2 or #4 on dual indicator.)	Check and fix either the transmitter or indicator power reversal.
(f) Indicator pointer takes a restrained position in the lower left quadrant of the dial. (Transmitter rotor seeks position 180° in error to that of the indicator.)	#1 and #3 disconnect plug terminals, or "G" and "1" terminal plate numbers, on the *indicator* are reversed. (#1 and #8 on dual indicator back motor.)	Check and fix indicator external wiring reversal.
(g) Indicator pointer takes a restrained position in top right hand quadrant of the dial. (Transmitter rotor seeks a position 180° in error of the indicator.)	#1 and #3 disconnect plug terminals, or "G" and "1" terminal plate numbers, on the *transmitter* are reversed.	Check and fix transmitter external wiring reversal.
(h) Indicator pointer takes a restrained position in the lower right hand quadrant of the dial. (Transmitter rotor seeks a position 180° in error to that of the indicator.)	#1 and #5 disconnect plug terminals, or "G" and "3" terminal plate letters, are reversed on the *indicator*. (#1 and #10 dual indicator back motor.)	Check and fix indicator external wiring reversal.

AUTOSYN AIRCRAFT WIRING TROUBLE TABLE (*Continued*)

TROUBLE	PROBABLE CAUSE	REMEDY
(i) Indicator pointer takes a restrained position in the top left hand quadrant of the dial. (Transmitter rotor seeks a position 180° in error to that of the indicator.)	#1 and #5 disconnect plug terminals, or "G" and "3" terminal plate letters, are reversed on the *transmitter*.	Check and fix transmitter external wiring reversal.
(j) Indicator pointer has rapid erratic movement, in an arc of approximately 100°, which develops into rapid spinning.	#2 and #3 or #5 disconnect plug terminals, or "A" and "1" or "3" terminal plate numbers, of the *indicator* are reversed. (#4 and #8 or #10 on dual indicator back motor.)	Check and fix indicator external wiring reversal.
(k) Indicator has rapid erratic movement in an arc of approximately 100° but does not spin.	#2 and #3 or #5 disconnect plug terminals, or "A" and "1" or "3" terminal plate letters, of the *transmitter* are reversed.	Check and fix transmitter external wiring reversal.
(l) Indicator pointer has reversed rotation, otherwise normal.	#3 or #5 disconnect plug terminals, or #1 or #3 terminal plate numbers, are reversed between the transmitter and indicator. (#8 or #10 dual indicator back motor.)	Check and fix the external wiring reversal.
(m) Indicator pointer has no movement with transmitter movement.	Power fails to reach both transmitter and indicator.	Check the following: #1 and #2 disconnect plug terminals; G and A terminal plate numbers; (#1 and #4 dual indicator back motor).
(n) Weak or erratic pointer movement of all Autosyn indicators in the ship.	Power supply voltage or frequency incorrect or unstable.	Check power supply input and output.

NOTE: With a grounded-secondary Autosyn installation, care must be exercised to be sure the interconnecting leads and power leads of the Autosyns are not reversed. As shown above, some of the lead reversals will force the transmitter rotors into mechanism-straining positions which may result in damage to the same. All wiring should be carefully checked before the power is turned on to avoid costly maintenance delay.

With the Autosyn units properly connected and the ship's power supply on, the Autosyn indicators should read within the following allowable zero errors for the various functions:

Fuel Pressure	± 0.2 lb./sq. in.
Oil Pressure	± 5.0 lb./sq. in.
Manifold Pressure	± 0.5″ Hg (between 25″ and 35″)
Oil Temperature	± 4° C. (Between 10° and 30° C.)
Tachometer	± 1/32″

When taking readings for zero position, with the engines not running, each transmitter and indicator should be tapped before reading.

There are certain definite and easily recognizable signs of trouble in the wiring, which were listed in the table on pages 145 and 146. It is suggested that these be very carefully studied by personnel charged with the service of the subject equipment.

Mechanical Connections

When it is definitely established that all wiring is correct, and the disconnect plug properly assembled, it should then be determined whether the mechanical connections to the engine or other mechanisms are correct and in good condition.

In connection with the mechanical elements of Autosyn units, there are certain points listed below which may be of assistance in identifying or eliminating difficulties.

Autosyn Motors (Both Indicator and Transmitters). Sticking or excessive friction generally denotes worn or corroded bearings or a broken jewel in a dual indicator.

Manifold Pressure and Fuel Pressure Transmitters. These units are almost identical in construction. Clogged, dirty connection lines are a possible source of trouble, and may cause the small damping screw of the pressure connection tubing inside the unit to become plugged.

If the unit is subjected gradually to full-range pressure, and the clutch between motor and mechanical element is observed to move only through a very small restricted arc, a

ruptured diaphragm, or diaphragm connection strap, may be indicated, necessitating repair or replacement of this part.

In this connection, it should be noted that the Autosyn power should always be switched on before starting the engines of the airplane. Switching the Autosyn power on after the engines are started imposes a very severe, sudden strain on the mechanisms and may cause damage.

Oil Pressure and Temperature Transmitters. In this case, again, if the unit is subjected to full-range pressure or temperature respectively, and is observed to move through only a restricted arc or zero arc, a broken Bourdon tube or capillary tube is indicated, necessitating replacement. The oil lines should be checked to see that they are not obstructed.

Tachometer Transmitter. Erratic operation or oscillation may be due to improper installation of the tachometer shaft, which should be carefully checked. No operation of the mechanical element of this transmitter indicates a probable broken shaft.

Rough or noisy operation indicates lack of proper lubrication, or worn bearings, which should be corrected at the instrument overhaul base.

Fuel Level Transmitter. Sticking, or no indication may be due either to gasoline tank cement on the float, or to a leaking float caused by long operation in any empty tank under severe vibration. Badly worn bevel gears, bearings, binding bushings, or ununiformly tightened flange bolts may also cause erratic operation of the transmitter.

The float arm length adjustment and the zero adjustment of the fuel transmitter should not be changed once the transmitter is properly installed. If improper indications should be encountered under full and empty conditions the alignment of the transmitter float arm with the tank axis should be checked. The range may be checked in any empty tank by attaching a string to the float arm and simulating full tank and empty tank conditions by pulling the other end of the string through one of the mounting flange holes. Care should be taken during this

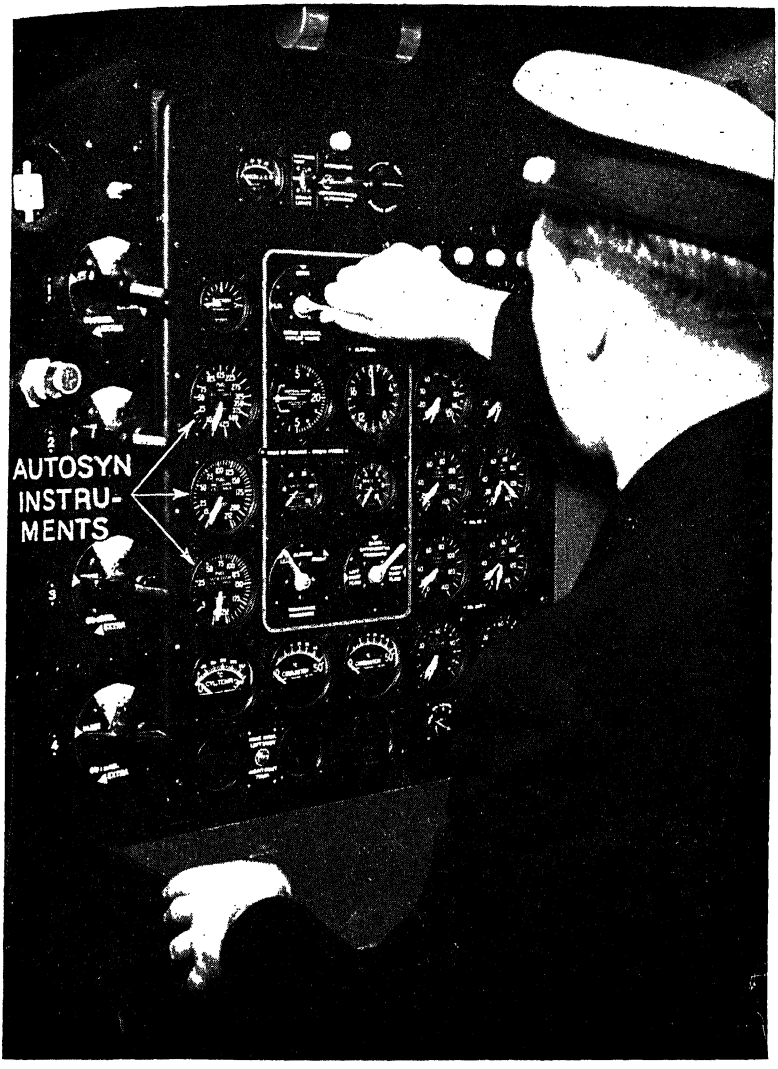


Figure 105. Pan American's New Strato-Clipper Introduces a New Idea in Instrument Panels

(Pan American Airways)

Here, at the Engineering Officer's post on the flight deck, are grouped two different sets of instruments—for two totally different purposes. The outer group on the board—around the white-outlined panel—are the normal engine instruments, and deal exclusively with conditions outside the airplane. The instruments on the inner panel deal exclusively with what is going on "in the parlor," as it were—they tell a constant story of the operation of the Strato-Clipper's automatic supercharging mechanism, and form one of the multiple safeguards to insure its unfailing functioning.

test to be sure the float is in a flat position on the bottom and on the top of the tank. It is important when tightening the mounting flange bolts to be sure they are tightened uniformly, otherwise the motor magnet cover may be cocked in position enough to interfere with the free movement of the magnet.

The power supply should be disconnected prior to making adjustments near the terminals of the Autosyn transmitter motor so as to eliminate the possibility of accidental spark ignition of any gas vapor.

For any service or adjustments to the internal mechanisms of Autosyn units, the faulty indicator or transmitter should be removed from the airplane and the work done in the instrument overhaul shop by a qualified instrument service man.

CHAPTER 15

ELECTRIC FUEL QUANTITY GAUGE

The electric type fuel quantity gauge is used to indicate the quantity of fuel contained in the tanks. It is ideally adaptable for airplanes that have more than one tank.

General Description

A tank transmitter unit is installed on each tank. (Tank units vary depending on the shape of the tank, internal obstructions, etc. They may be installed on top, side, bottom or any other position on tank that will provide the most practicable installation arrangement.) Each tank unit contains a resistance strip and a movable contact arm, the position of which is varied by the motion of a float in the tank. This position is transmitted electrically to an indicator graduated in gallons or other form of measurement. Fuel leakage from the tank is prevented by a metal bellows at the point where the float movement is carried through to the resistance strip unit. Various type indicators are in use. For instance, there are single, double and multiple scale indicators. Single scale indicators may be used to gauge the contents of more than one tank, in which case a suitable selector switch is installed in the gauge circuit. Double and multiple scale indicators comprise units having a separate electrical mechanism for each dial scale and, consequently, provide gauge readings for two or more tanks (depending upon the type indicator selected) without resorting to the use of a selector switch.

Operation

Figure 106 shows the electrical arrangement of a single tank unit and a single scale 90° type indicator. The contact shoe (C) in the tank unit is caused to move over the resistance strip (R)

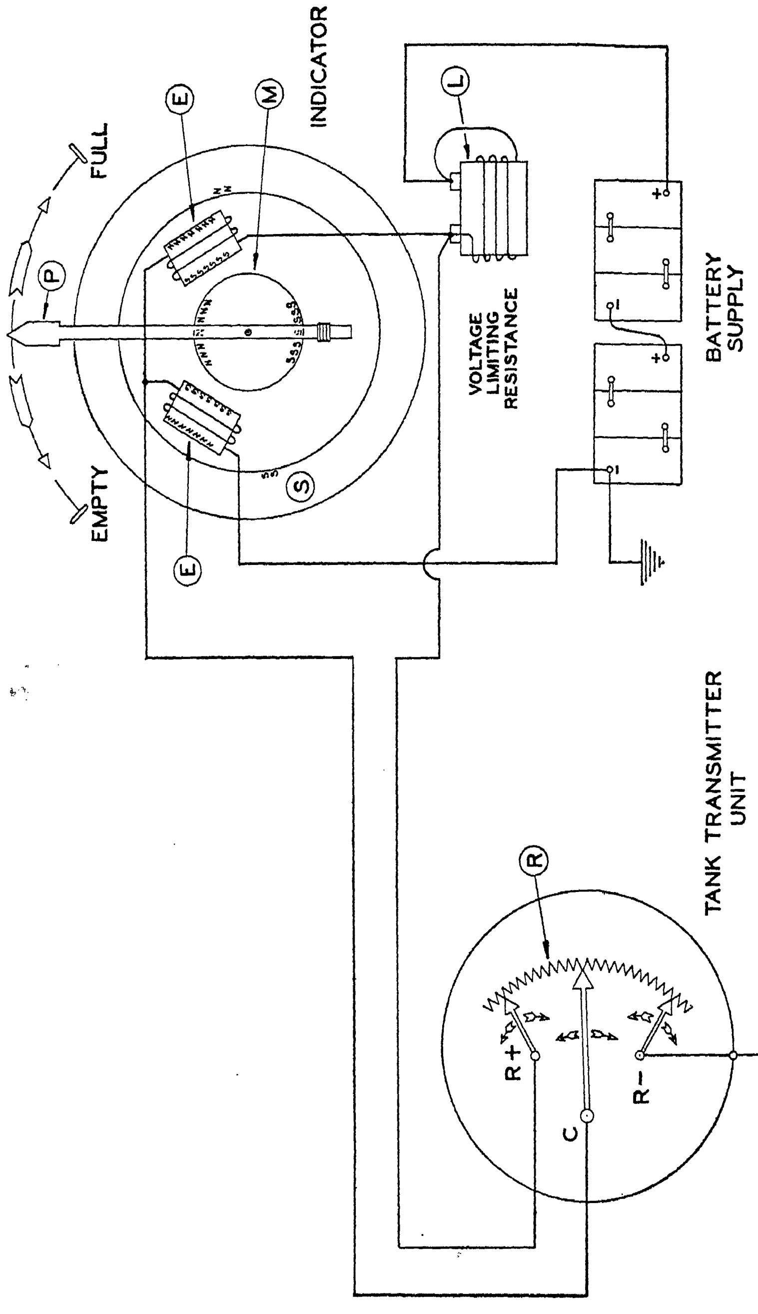


Figure 106. Liquidometer Single-Tank Unit Electrical Arrangement
(The Liquidometer Corp.)

through suitable leverage by the movement of a float in the tank. (See Figure 108.) The indicator consists of a pointer (P) attached to a magnetic iron rotor (M) mounted in association with two electro-magnets (E) and (E). These magnets are connected to the tank unit by wiring and the system is grounded as shown. The current distribution is varied at the tank unit through the movement of contact shoe (C) over resistance strip (R) and the current thus distributed excites the two electro-magnets (E) and (E) which in turn move the magnetic iron rotor to which the pointer (P) is attached. A magnetic force (S) serves to bring the pointer off the empty end of the scale when the current is off. The voltage limiting resistance (L) protects the system from overload should any of the tank unit leads be short circuited.

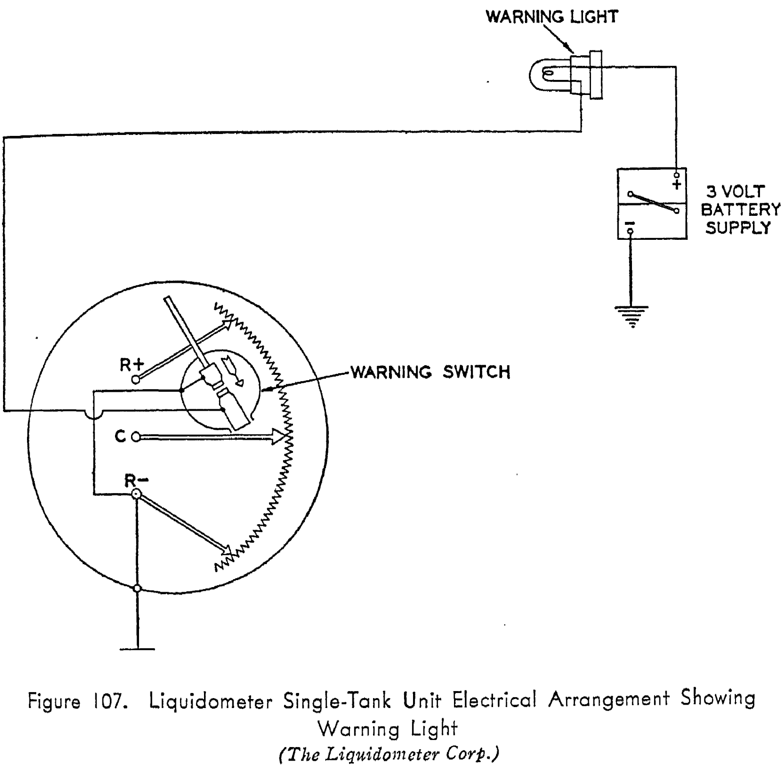
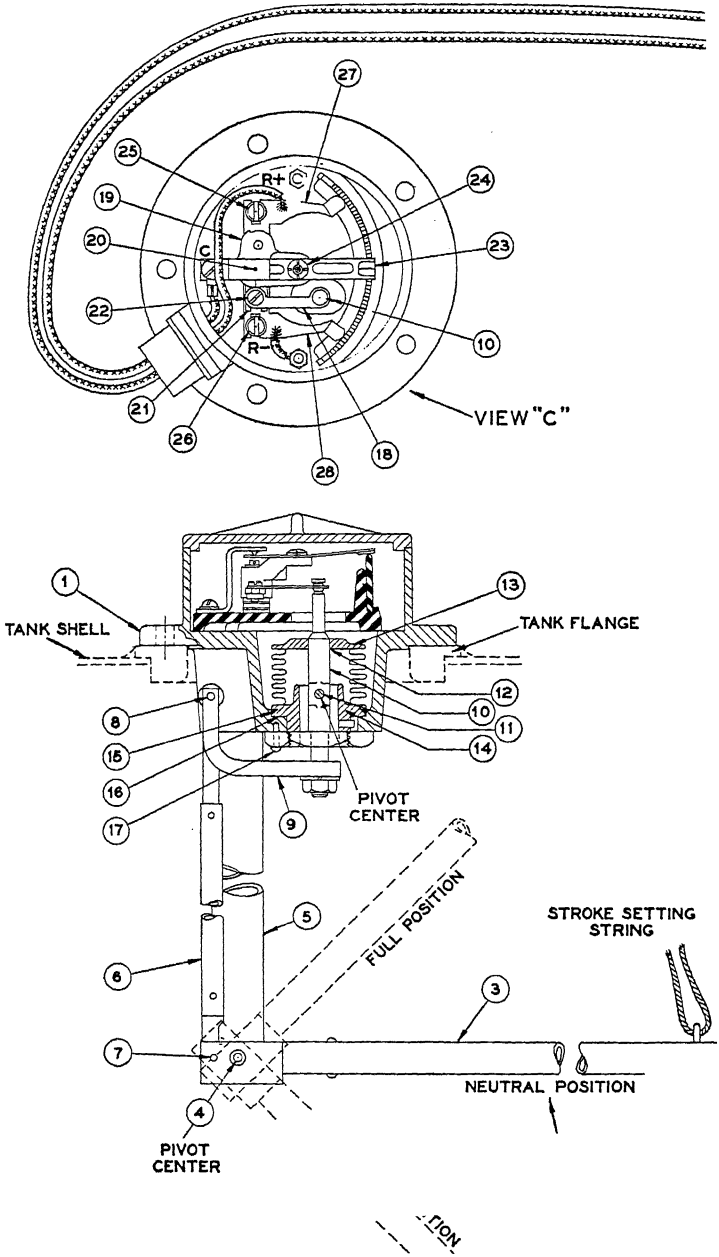


Figure 107. Liquidometer Single-Tank Unit Electrical Arrangement Showing Warning Light
(The Liquidometer Corp.)


27
25
R+
19
24
20
C
23
22
10
R-
21
26
28
18
VIEW "C"
1
13
TANK SHELL
TANK FLANGE
12
10
8
11
14
15
16
17
9
PIVOT CENTER
FULL POSITION
STROKE SETTING STRING
5
6
3
7
4
NEUTRAL POSITION
PIVOT CENTER

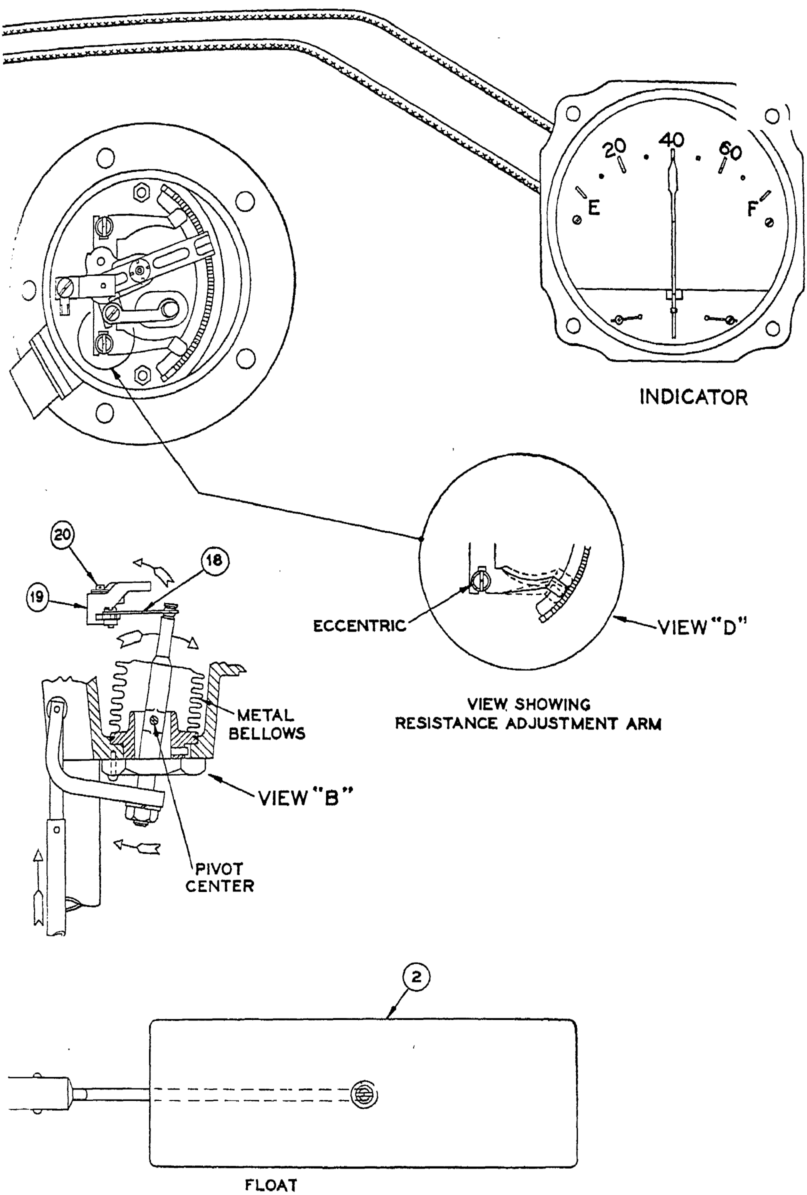


Figure 108. Liquidometer Electrical Fuel Contents Indicating Unit
(The Liquidometer Corp.)

It will be noted that the leads R+ and R− contact resistance strip (R) at each end through an adjustable shoe. This adjustment varies the effective resistance value of strip (R) and affords a convenient means for adjusting the pointer position at either end of the dial scale in conformity with the position of the float at the top and bottom of the tank.

Liquidometer tank units can be provided with a sealed low level warning switch which is connected to a lamp to indicate a predetermined low liquid level. Figure 107 shows the electrical arrangement used where low level warning signal switches are employed. The movement of arm (C) opens and closes the contact in the warning switch. An adjustment is provided so that the switch action can be set to give the warning at the desired liquid level.

Figure 108 shows the mechanical action of a tank unit arranged for mounting on the top of a tank. As previously stated tank units may be installed on the top, bottom, side or any other tank position that provides the most suitable installation arrangement. It will be noted that the housing (1) is attached to a tank flange. The float (2) rides the liquid surface and moves float arm (3) which is pivoted at (4). Pivot (4) is supported by fulcrum support (5) which in turn is attached tc housing (1). The push rod (6) is pivoted to the float arm at (7) with the opposite end pivoted at (8) to short arm (9). The latter is attached to rocker arm (10) which is pivoted at (11). The rocker arm (10) is sealed at (12) to metal bellows head (13), and the lower end of the bellows is sealed to pivot supporting head (14) at (15). The bellows head (14) is drawn in place to form a seal at (16) by nut (17) by means of a suitable locating and locking arrangement. Thus, it can be seen that liquid, vapor or air from the tank cannot pass through the bellows.

Due to the mechanical linkage a movement of the float will cause a rocking movement of lever (10). View "B" illustrates the position of lever (10) when the float is at the tank bottom position. A link connection (18) is used to connect the upper end of rocker arm (10) and variable resistance shoe support (19) which is free to move around bearing (20).

Referring to view "C," slotted arm (21) is fixed to shoe support (19) which is free to move at bearing (20). By adjusting the distance between link bearing (22) and bearing (20) the amount of travel of shoe (23) can be set so that the shoe will move over the resistance strip the required amount when the float is moved to touch top and bottom of the tank.

Slotted eccentrics (25) and (26) are provided to control the position of the electrical take-off shoes (27) and (28). (See enlarged view "D"). A means is provided for moving the float from bottom to top of tank so that the indicator pointer travel may be adjusted to conform with the float travel. (See "stroke setting string" on Figure 108.) In some instances, however, the use of a stroke setting string is not practicable and a wire form or some other device may be used through a separate opening in the tank in order that the float may be lifted up and down during the stroke setting operation.

Dial Graduations

Dials are graduated in two ways. (1) A blank dial is placed on the indicator and its various positions are marked as various amounts of fuel are poured in the tank. The dial is then sent to The Liquidometer Corporation for a finished dial. (2) A tank capacity curve or chart may be sent to The Liquidometer Corporation and this information will be used to make the proper dial.

A dial can only be used for the tank for which it was graduated or a tank of like shape and capacity. It follows, therefore, that a dial should never be taken from one indicator and placed on another indicator unless it is definitely known that the two tanks are exactly alike.

Installation

The installation procedure varies with the different types of tanks. It is therefore impossible to set forth a hard and fast procedure which would cover all types of installations. For this information The Liquidometer Corporation should be consulted.

Dial Change Indicator and Selector Switch Combination Unit

There also is a unit known as the "Dial Change Indicator and Selector Switch Combination Unit" which is adaptable for airplanes where there are a number of tanks of different capacities. In this unit a separate dial is provided for each tank. The selector switch and indicator elements are combined so that when the selector switch knob is turned to a certain tank position the dial calibrated for that tank automatically comes into view.

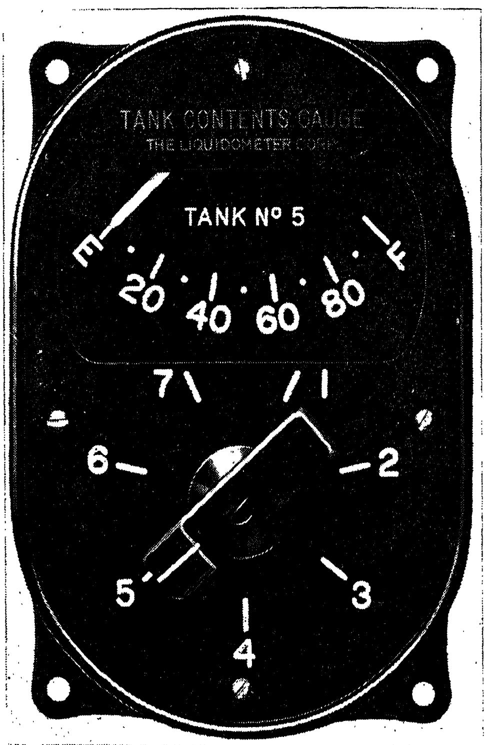


Figure 109. Liquidometer Dial Change and Selector Switch Combination Unit
(The Liquidometer Corp.)

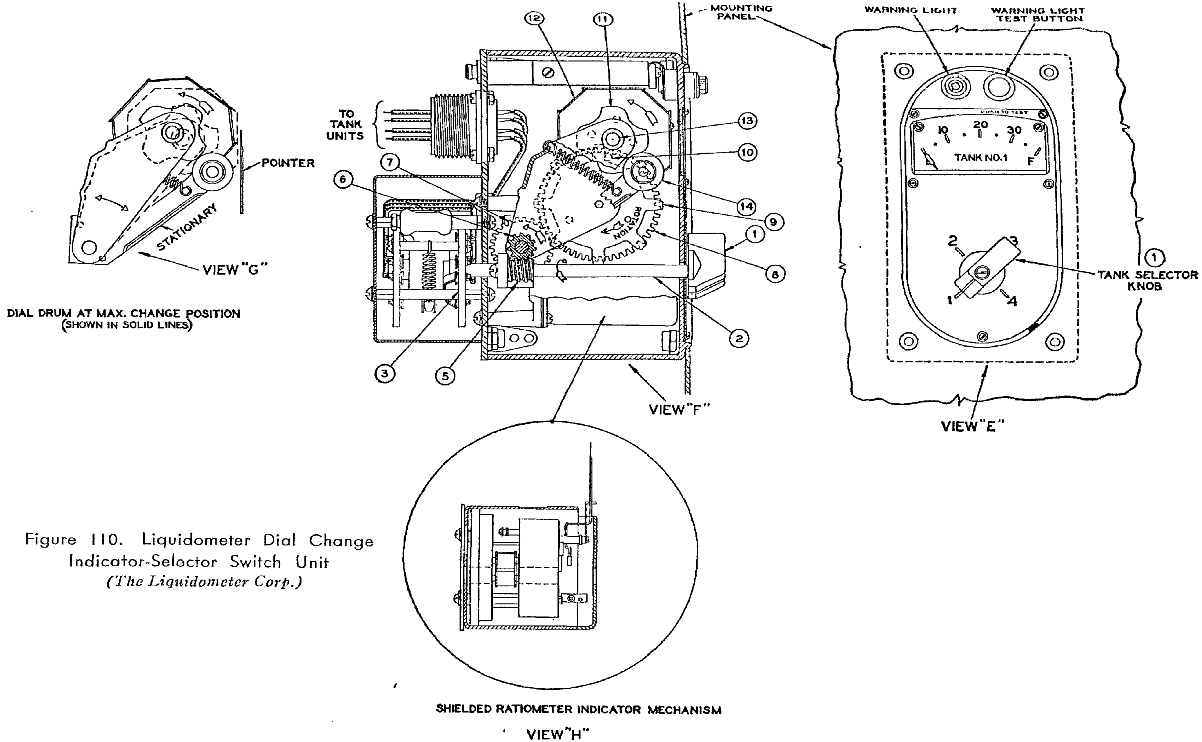


Figure 110. Liquidometer Dial Change Indicator-Selector Switch Unit
(The Liquidometer Corp.)

Figure 110 shows the mechanical arrangement of the Dial Change Indicator and Selector Switch Combination Unit. View "E" shows the unit mounted on a panel. When selector switch knob (1) is turned it moves the contacts in the selector switch and also controls the dial change mechanism so that the desired dial comes into view.

Referring to view "F" it will be noted that knob (1) is connected to shaft (2) which extends through to selector switch (3). Attached to shaft (2) is worm (5) which engages gear (6). The same shaft that supports gear (6) has a second gear (7) which meshes with gear (8). Attached to the latter is a sprocket (9) which engages pins (10) which in turn are attached to cam (11). Cam (11) is attached to dial drum (12) which is free to rotate on bearing (13). Cam (11) rides rotor (14). Consequently, it will be seen that when the knob (1) is turned the contacts in the selector switch are shifted and at the same time the gear connection to shaft (2) causes the cam (11) to turn and push the dial drum away from rotor (14) and simultaneously dial drum (12) turns to a new indexed position.

View "G" shows the action resulting from the cam movement. View "H" is an illustration of the indicator electrical mechanism.

Figure 111 shows the wiring arrangement of a Dial Change and Selector Switch Combination Unit having a four-sided dial drum and including a common low level warning light.

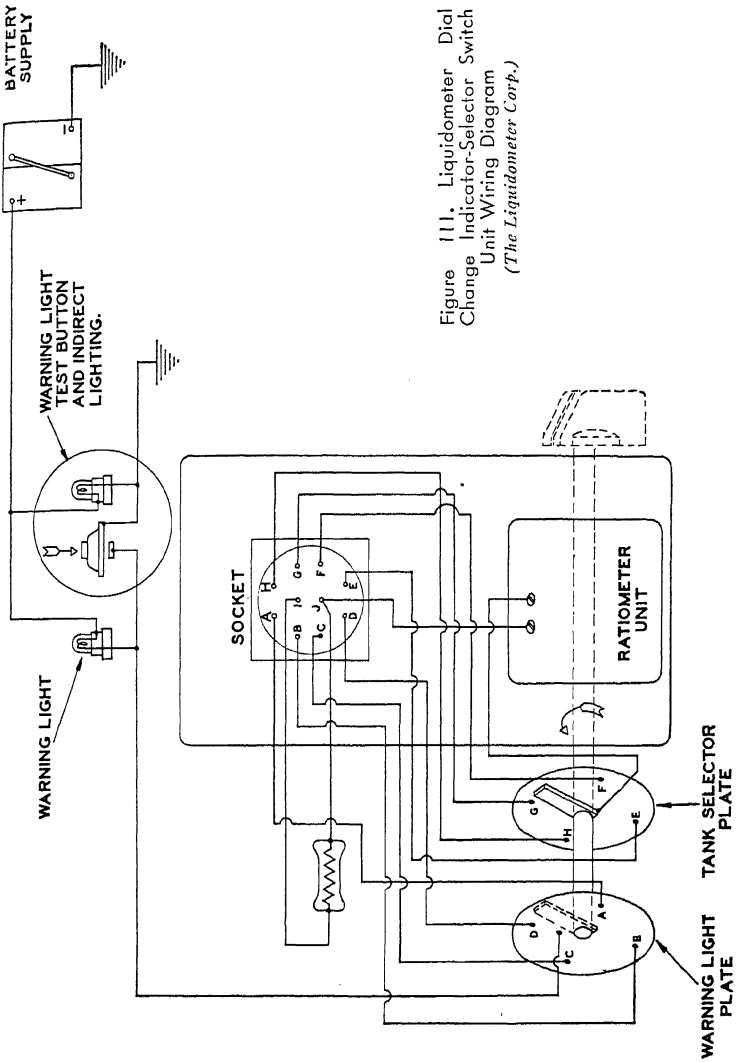


Figure 111. Liquidometer Dial Change Indicator-Selector Switch Unit Wiring Diagram
(The Liquidometer Corp.)

CHAPTER 16

AIRCRAFT CLOCK

Pioneer-Elgin clocks are designed to meet the special requirements of a dependable aircraft instrument. They are made with small AN dimensions, the same as other Pioneer standard instruments with a 2¼″ case. Ruggedly constructed with extra heavy movement plates and seven jewels, these clocks are substantially protected against vibration effects and landing shocks. They mount flush with the surface of the instrument board, with a combination winding and setting knob conveniently mounted in front.

Eight-Day Movement. The eight-day movement serves to insure the operator of continuous clock operation and utility both on the ground and in flight.

Easy Winding. The large knob below the face lends ease to the winding or setting operation which is a great help to heavily gloved hands.

Flying with the Aircraft Clock. This clock has a large sweep second hand, which provides an accurate means of timing and also serves to indicate the continuous operation of the clock. An accurate time check is essential in "instrument" and "contact" flying, since this is the only means the pilot has for accurately determining his ground speed and hence his estimated time of arrival at his destination or over subsequent "check points." Correct ground speed and time calculations are a real aid in reducing the complexities of traffic control and lend substantial significance to "proposed" and "altered flight plans." Fuel consumption calculations and accurate "Endurance forecasts" are essential for safe flying and are greatly facilitated by a dependable means of measuring the flight-time.

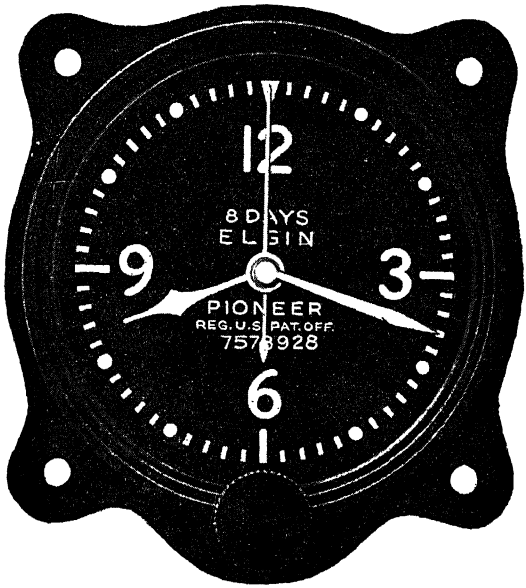
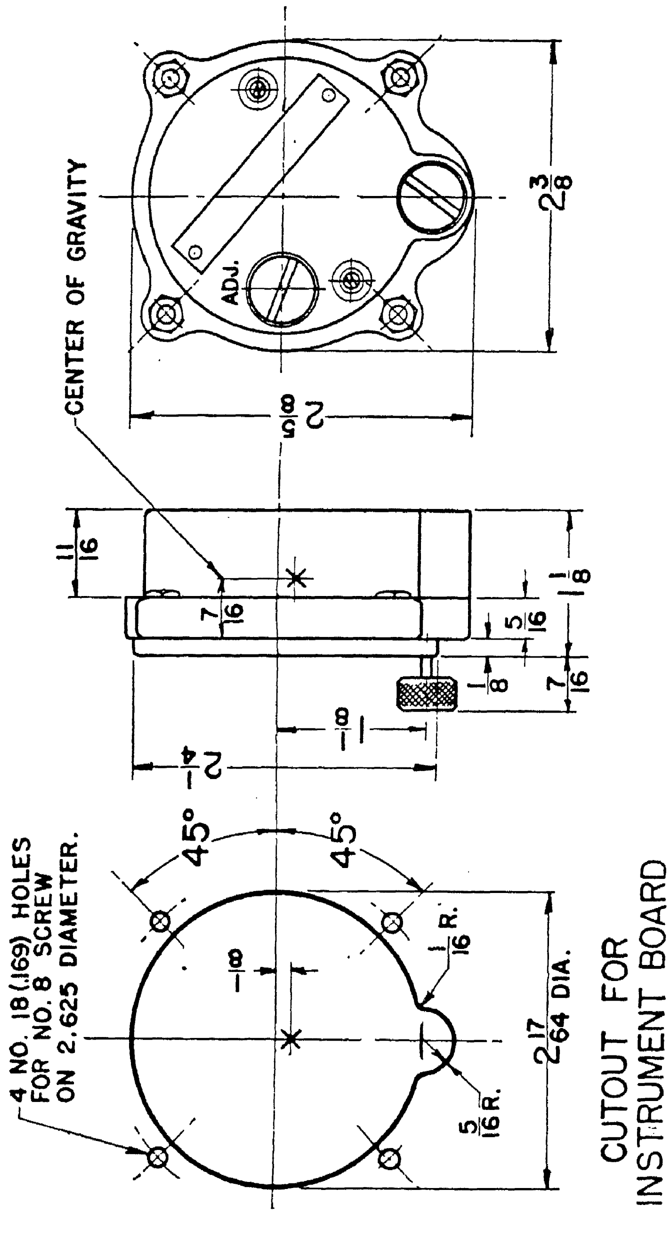


Figure 112. Pioneer-Elgin Clock Type 3310-2
(Pioneer Instrument Division of Bendix Aviation Corp.)

Test Specification

The clock shall be run for one day to allow it to settle down. The clock then shall be fully wound and its daily rates determined for a period of three consecutive days. The clock shall not be rewound during this test period. The average of the daily rates for the three days immediately following the winding shall not exceed 45 seconds. The variation of any daily rate, during this period, from the average daily rate (for three days) shall not exceed 30 seconds. The test shall be made with the dial in vertical position with the 12 mark at the top.

Installation. This clock must be mounted on a panel suitably damped from vibration. The maximum amplitude (total movement) of vibration should not exceed 0.008″ at normal engine frequencies. By removing the case screw on left-hand side of the back of the clock case, regulating adjustments can be made. These should be done by a skilled instrument mechanic only.



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CHAPTER 17

AIR-SPEED INDICATOR

The air-speed indicator is essentially a diaphragm-actuated air-pressure instrument, which measures the differential between the impact or (pitot) pressure of the air through which the aircraft is flying and the static or (still-air pressure). The source of the pressure differential is the pitot-static tube.

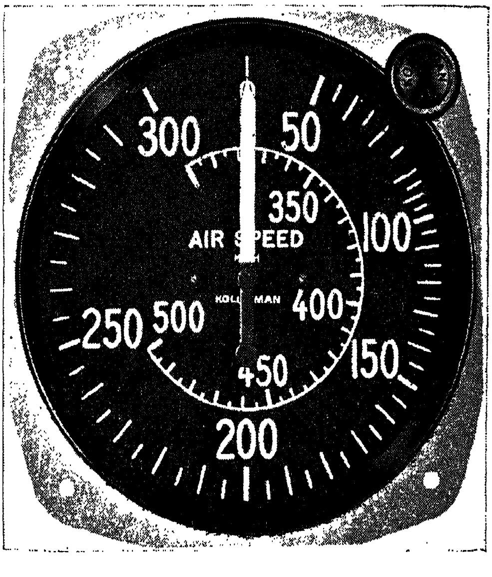


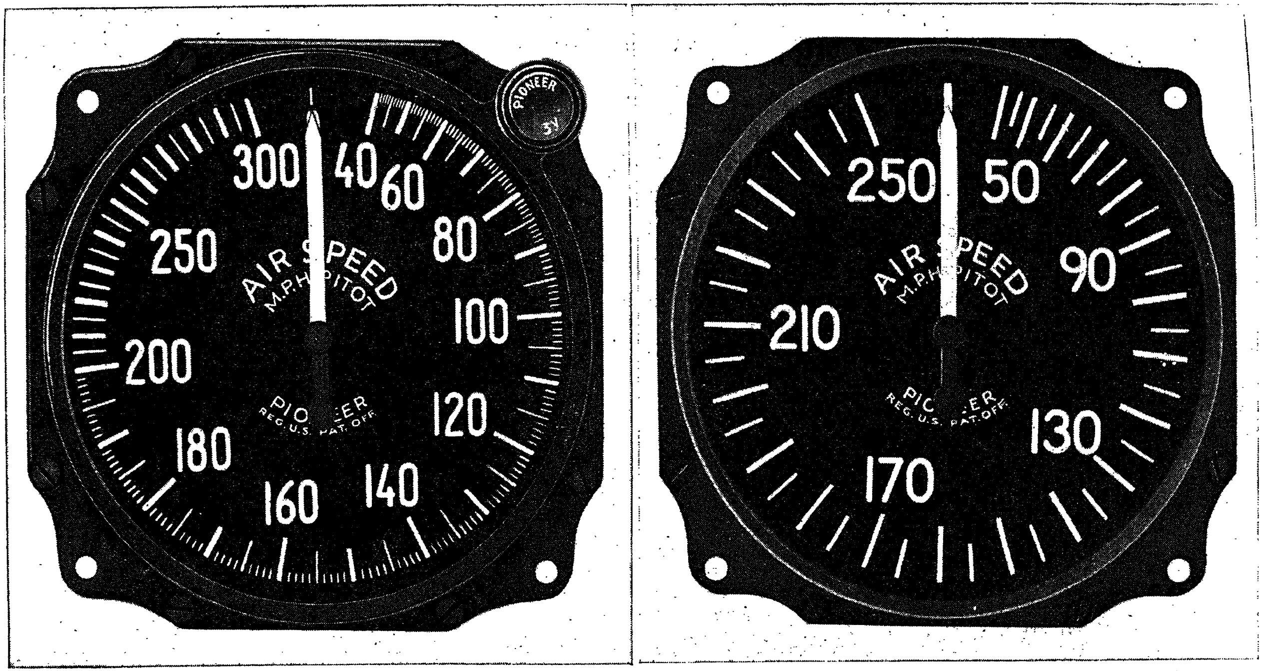
Figure 114. Kollsman Type 657SD-011
(Kollsman Instrument Division of Square D Co.)

The air-speed indicator is used in conjunction with the turn and bank and rate of climb indicator instruments to make up the "primary flight group." It is the first member of this important group. The indications of these three instruments are all that is required to enable the pilot to regain a level straight flying position from any attitude his airplane might take.

When the sensitive altimeter, compass and directional added to this "primary flight group," a flying instruments results.

oneer Type 1415-3B (Rotatable Dial)
(Pioneer Instrument Division of Bendix Aviation Corp.)

The density of the air decreases with increase of altitude and will introduce a variation between the readings of the air-speed indicator and the true air-speed, which is proportional to the increase in altitude. Thus, as the altitude increases, the differential pressure in the indicator will decrease and the indicated air-speed will be lower than the actual or true air-speed.



Type 1401-1T Figure 116. Pioneer Types Type 1402-3D
(Pioneer Instrument Division of Bendix Aviation Corp.)

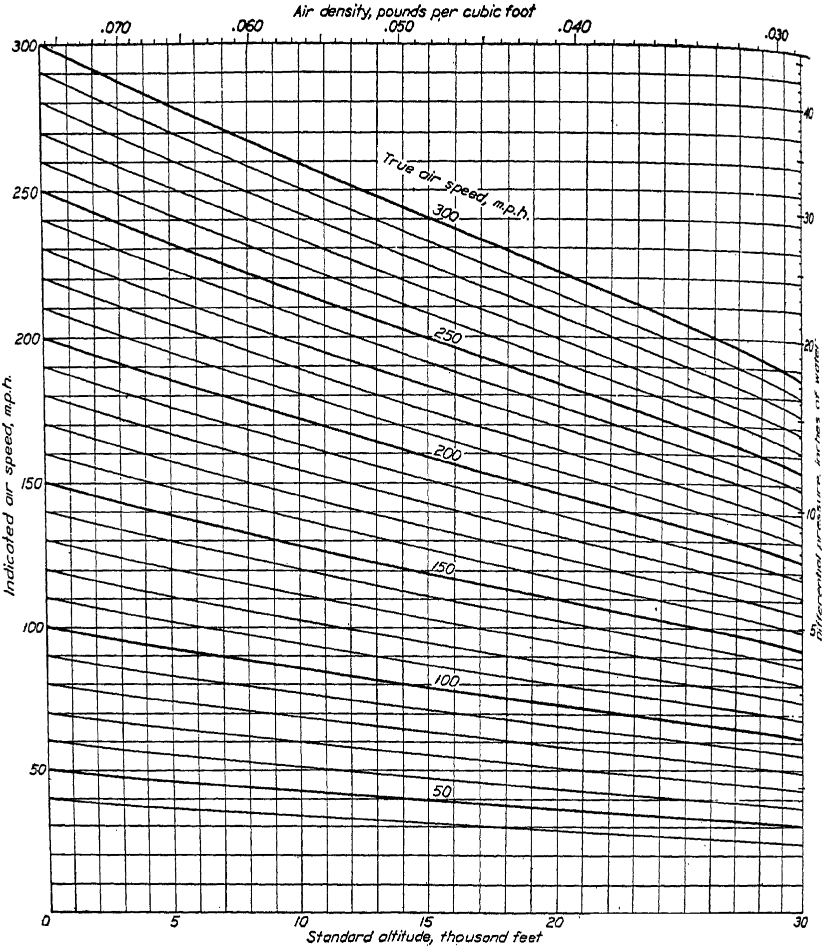


Figure 117. Chart for Determination of True Air-Speed from a Given Indicated Air-Speed and Standard Altitude (N.A.C.A. Report No. 420)

Figure 117 provides a very simple method of deriving the true air-speed from the indicated air-speed at altitudes up to 30,000 feet and with an accuracy sufficient for all practical operations. With indicated air-speeds as ordinates and altitude (corrected to standard) as abscissae, the true air-speed is read directly at the point where the two intersect, by interpolating at a glance with respect to the nearest line marked "true air-speed" running across the chart.

Operation of the Air-Speed Mechanism

While Pioneer and Kollsman air-speed indicators function in the same manner, the internal construction varies slightly.

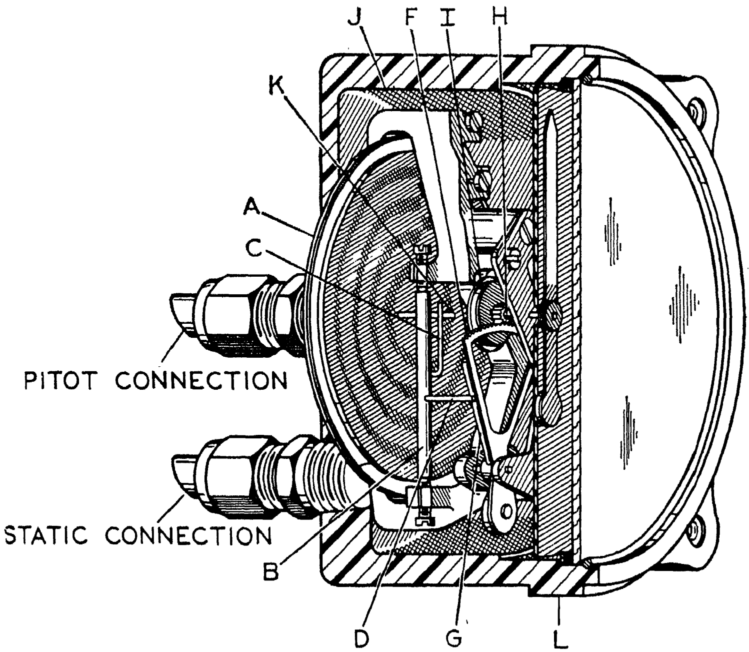
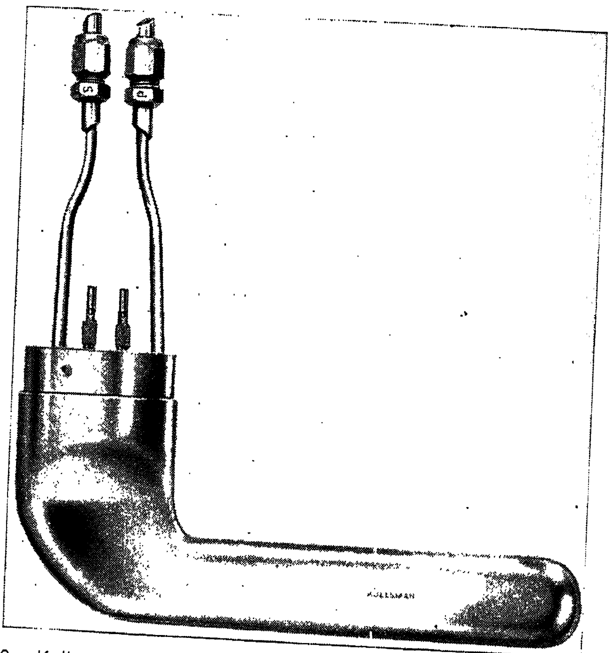


Figure 118. Kollsman Type 657SD-011
(Kollsman Instrument Division of Square D Co.)

The Kollsman air-speed indicator consists primarily of an airtight diaphragm assembly (A) and a mechanism for multiplying its deflection. The mechanism is composed of a rocking-

shaft assembly (B) with diaphragm lever (C) and (D), a sector (F) with sector lever (G), and pinion (H). A hairspring (I) secured to the h anchored to the mechanism body (J) removes chanism and holds the diaphragm lever diaphragm bridge (K). The entire airtight case (L). The pitot tube is conn the diaphragm and the static tube to the

A- the speed of the airplane increases, the the diaphragm causes the latter to expand. The rocking picks up the motion by means of its diaphragm lever and in turn transmits this motion through the long lever, to the sector, and finally to the hand-staff pinion. The pointer fastened to the hand-staff indicates air-speed in knots, miles per hour, or kilometers per hour.



119. Kollsman Electrically Heated Pitot-Static Head Types 172K, 172M, 172N, 372B, 372C (Vertical Mounting)
(Kollsman Instrument Division of Square D Co.)

Operation of the Pitot-Static Tube

The pitot-static tube performs the function of transmitting true dynamic (pitot) and static pressures to the air-speed indicator as well as true static pressure to the rate of climb indicator and the altimeter.

Since there is such a wide variation in temperatures and relative humidities encountered in scheduled flying, the necessity for adequate protection against ice accumulation affects the problem of delivering true pressures to the flight instruments, inasmuch as the greatest need for instrument accuracy arises.

It is therefore necessary to have a pitot-static tube which is electrically heated, noncorroding and moisture proof. Pioneer and Kollsman both manufacture excellent pitot-static tubes.

General Description of Pioneer Pitot-Static Head

The Pioneer de-icing, electrical heating unit contains a specially selected nickel alloy heating filament which is covered with an impregnated electrical insulator and sealed in a "Monel" tube or sheath. The purpose of this added covering and sealing protection is to give the filament sufficient structural support to prevent any possibility of filament rupture under extreme vibration conditions and effectively prevent the corrosive effects resulting from moisture seepage. The tube-covered heating filament itself is wound in a reversing spiral to neutralize its magnetic field. The external electrical outlets of the heating unit are sealed in special "Kovar" to glass, moisture-proof, insulated terminals that are not affected by extreme temperature changes. The power requirement is 100 watts maximum for all operating conditions with either the 24-volt or 12-volt types.

It is necessary to have an efficient drainage. This is shown best by noting Figure 121. The large opening is located at the head of the tube for the admission of pitot or dynamic pressure. Since water will also enter this hole, a drain hole is located at the back of the dynamic pressure chamber to permit water drainage under dynamic pressure. The pitot-pressure line is vented to the front of the dynamic pressure chamber, at the head, through a baffle connection which permits the dynamic

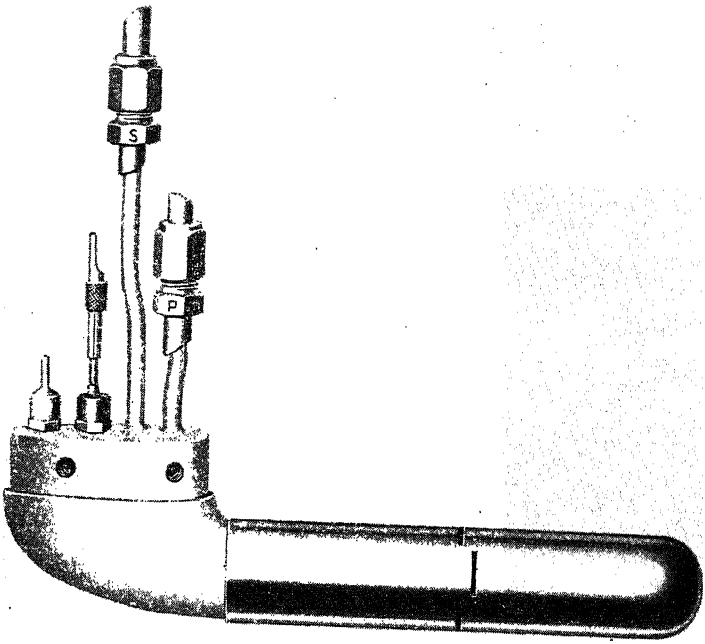


Figure 120. Pioneer Electrically Heated Pitot-Static Head Types 3202, 3203, 3218, 3220 (Vertical Mounting) *(Pioneer Instrument Division of Bendix Aviation Corp.)*

pressure to enter the pressure tube without the water. This gives complete drainage without the necessity of a "trap."

The static-pressure chamber is located immediately aft of the dynamic pressure chamber and is vented to the atmosphere through slots. To overcome static-pressure inaccuracies caused by the airplane "yawing," "pitching" or "mushing," the static pressure slots are distributed around the full diameter of the tube body. These slots also supply the water drainage for the static-pressure chamber. The static-pressure tube is located in the top at the back end of the static-pressure chamber so as to eliminate any water trouble.

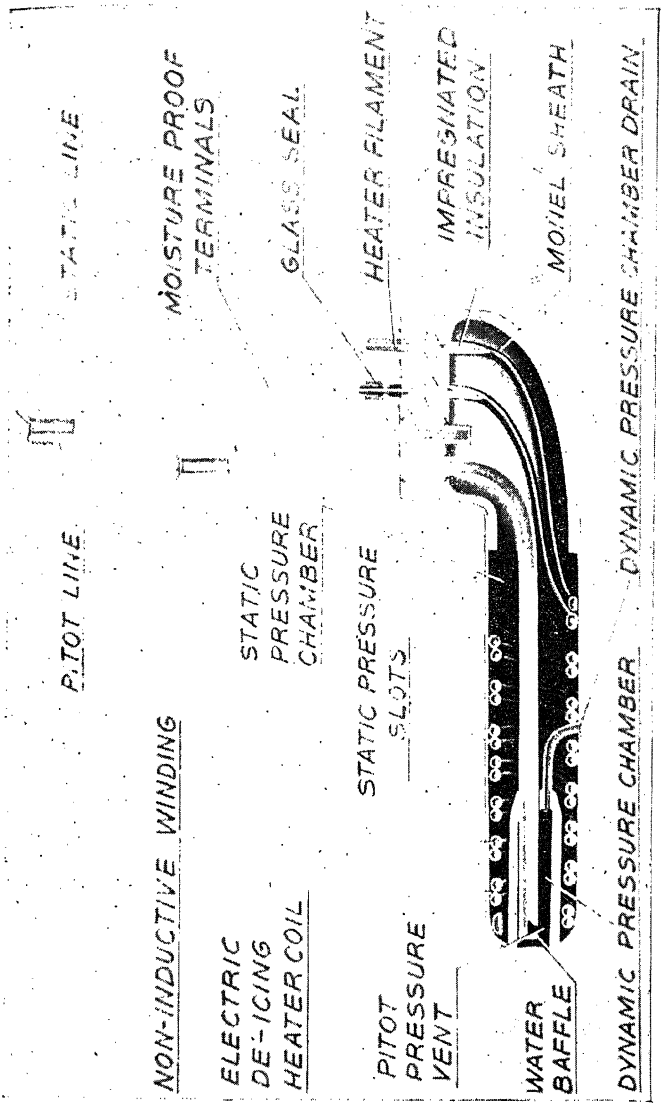


Figure 121. Cut-Away Section of Pioneer Weather-Proof Pitot-Static Tube
(Pioneer Instrument Division of Bendix Aviation Corp.)

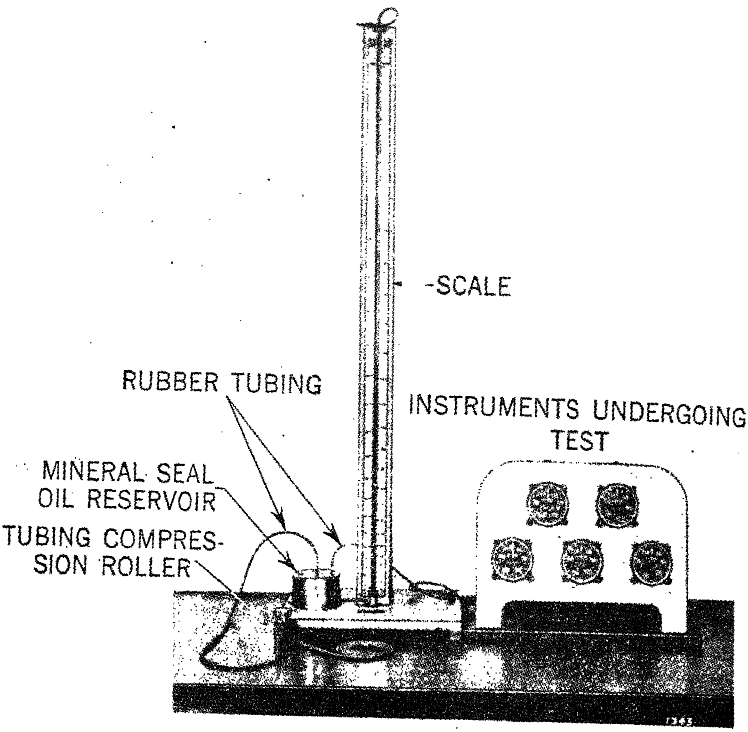


Figure 122. Pioneer Air-Speed Indicator Test Apparatus Manometer Type E-415
(Pioneer Instrument Division of Bendix Aviation Corp.)

Test Apparatus

The manometer, as illustrated, is a reservoir type, using mineral seal oil as a liquid. It is provided with scales reading in miles per hour, knots, or inches of water. Flexible rubber tubing is used to connect the instrument under test to the pressure chamber. Another length is used in creating pressure in the chamber. To create the varying pressures, there are two vise rollers slightly apart but with only enough clearance to prevent an air leak in the tubing when introduced between them.

Directions for Testing Indicator. Attach one end of the rubber tubing to the pitot or pressure opening of the indicator

under test. The other end is attached to the outer connection of the manometer pressure chamber. A longer length of tubing is attached to the center connection of the chamber, and the other end fed into the roller by turning the knob designed for this purpose. As the knob is rotated, an air pressure is produced in the tubing which builds up in the pressure chamber and exerts equal pressure on the manometer and the instrument under test. In this manner, the manometer registers the pressure on the instrument diaphragm. By building the pressure up to various readings on the manometer and gently tapping the instrument under test, a check may be made on the accuracy of the corresponding indication of the air-speed indicator.

For all types of instruments other than those specified the manufacturer's Test Specification Books should be followed.

Whenever the pressure and temperature existing at the time of the test are not specified definitely, it is understood that the test is to be made at atmospheric pressure (approximately 29.92″ of mercury) and at room temperature (approximately plus 20° C.). When tests are made with atmospheric pressure or room temperature differing materially from the above values, proper allowance shall be made for the difference.

Except where otherwise specified, the instrument shall be tested in an upright vertical position and shall be lightly vibrated or tapped before a test reading is taken.

Individual Tests. The air-speed indicator shall be subjected to the following tests in the order given below:

(a) Scale Error Test. The instrument shall be tested for scale errors at the points of the scale indicated by asterisks in Table II. The test shall be made by subjecting the instrument to the pressures specified to produce these readings, first with the pressures increasing, then with the pressures decreasing. With pressures increasing, the pressure shall be brought up to, but shall not exceed, the pressure specified to give the desired reading, and with pressures decreasing, the pressure shall be brought down to, but shall not fall below the pressure specified to give the desired reading. The errors at the test points shall not exceed the tolerances specified in Table II.

(b) Friction Test: The instrument shall be tested for friction at every other one of the points indicated by an asterisk in Table II, beginning with the first starred point. The pressure shall be increased so as to bring the pointer approximately to the desired reading, and then held constant while two readings are taken, the first before the instrument is tapped, the second after. The difference of any two such readings shall not exceed the tolerance specified in Table I. The pointer shall move smoothly while the pressure is varied uniformly without vibration of the instrument. This test may be combined with the test for scale error.

(c) Position Error Test. The change in reading produced by tipping the indicator from the vertical to the horizontal position or 90° to the right or left while the instrument is being tapped shall not exceed the tolerance specified in Table I. This test shall be made at every fifth one of the points of the scale indicated by an asterisk in Table II, beginning with the first starred point.

(d) Leak Test. A suction sufficient to produce approximately full scale deflection of the pointer shall be applied to the static connection of the indicator, at which point the connection tubing shall be pinched off or otherwise completely sealed. During a period of one minute, the pointer shall not change its position more than the tolerance specified in Table I. The suction shall be released and a pressure sufficient to produce approximately full scale deflection of the pointer shall be applied to the pitot connection of the indicator at which point the connection tubing shall be pinched off or otherwise completely sealed. During a period of one minute the pointer shall not change its position appreciably.

Table I

Tests	Tolerance and Test Points (m.p.h.) Pioneer 1401–1402
Friction Tolerance	3.0
Position Error Test Tolerance	2.5
Leak Test Tolerance	3.0

TABLE II

Test Point	Tolerance (m.p.h.) Pioneer 1401–1402
65*	2.0
120	2.0
170*	2.5
220	4.0
260*	4.0
300	4.0

Directions for Testing Pitot-Static Tube. (a) The electrical circuit of each pitot-static tube shall be tested to determine whether the heating element in the tube is operating satisfactorily.

(b) The impact pressure openings shall be sealed and a test manometer connected to the impact connection, and a pressure of 10″ of mercury applied. No leaks shall be apparent.

(c) The static openings of the pitot-static tube shall be sealed and a test manometer connected to the static connection. No leaks shall be apparent when a pressure of 10″ of mercury is applied.

(d) Each pitot-static tube shall be subjected to electrical tests at commercial frequency and alternating current of 550 volts between each terminal and ground for a period of 60 seconds.

Pitot-Static Tube Installation

The air-speed indicator should be mounted with the primary flight instruments (turn and bank, rate of climb indicators, and sensitive altimeter). This group should be within the unobstructed view of the pilot.

For maximum performance and life, it is recommended that the instrument be mounted on a panel suitably damped from vibration. The maximum amplitude (total movement) of vibration should not exceed 0.008″. When the instrument is installed in the panel, a suitable length of non-magnetic flexible tubing (at least 10″) must be connected between the instrument and the connecting tubing.

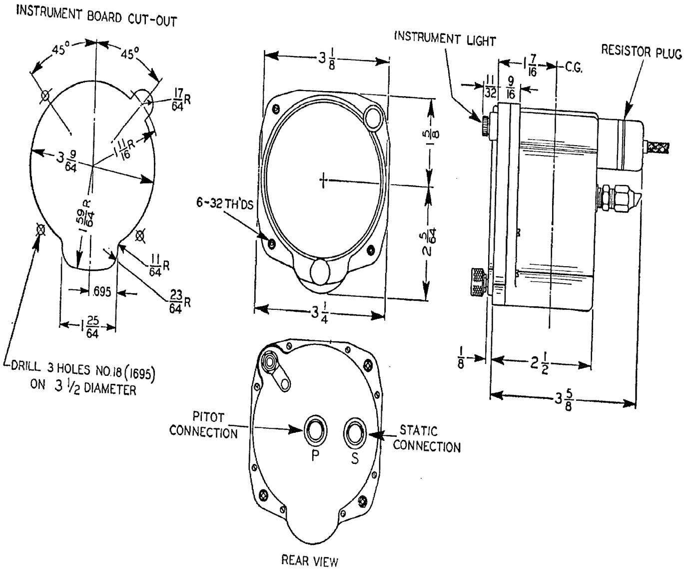


Figure 123. Kollsman Type Pitot-Static Tube Instrument In
(Kollsman Instrument Division of Square D Co.)

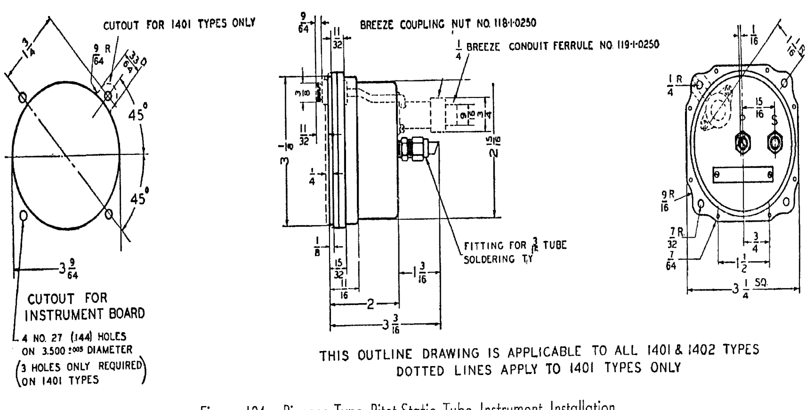


Figure 124. Pioneer Type Pitot-Static Tube Instrument Installation
(Pioneer Instrument Division of Bendix Aviation Corp.)

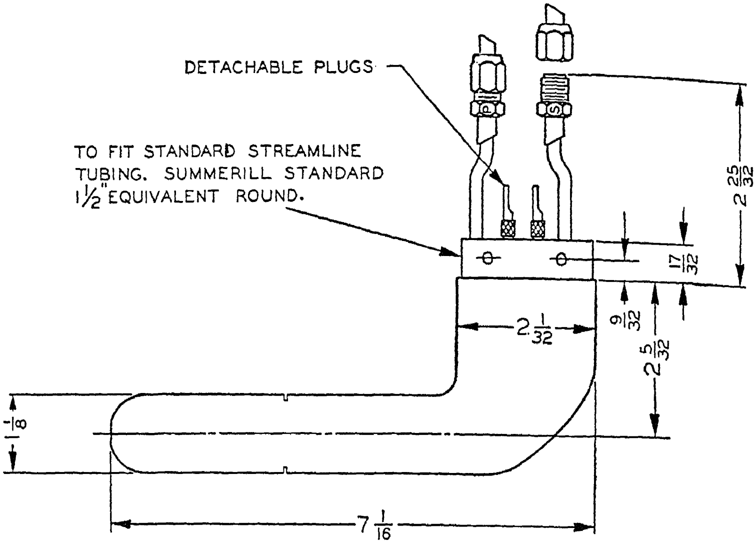


Figure 125. Kollsman Two-Wire Types 172K-172L-172M-172N-372B-372C (Vertical Mounting)
(Kollsman Instrument Division of Square D Co.)

Metal tubing, with a nominal diameter of 3/16", should be used to connect the air-speed indicator to the pitot-static tube. The fitting marked "P" on the back of the case must be connected to the pressure (velocity head) fitting on the pitot-static tube. Likewise, the fitting marked "S" must be connected to the static pressure fitting on the pitot-static tube. The tubing should be run as straight as possible, avoiding bends of small radius or loops which might cause water traps or constrictions in the lines. The lines should also be suitably clamped to the aircraft structure to avoid large amplitude vibrations. A pet-cock, or other suitable drain, should be accessibly installed at the lowest point of each connecting tube line.

The connections of the pitot-static tube and the air-speed indicator are marked "P" (Pressure) and "S" (Static). *Care must be taken* to be sure the tubing runs between like-lettered connections.

Before making final connections, both lines should be tested for the absence of leaks and constrictions. This may be done by

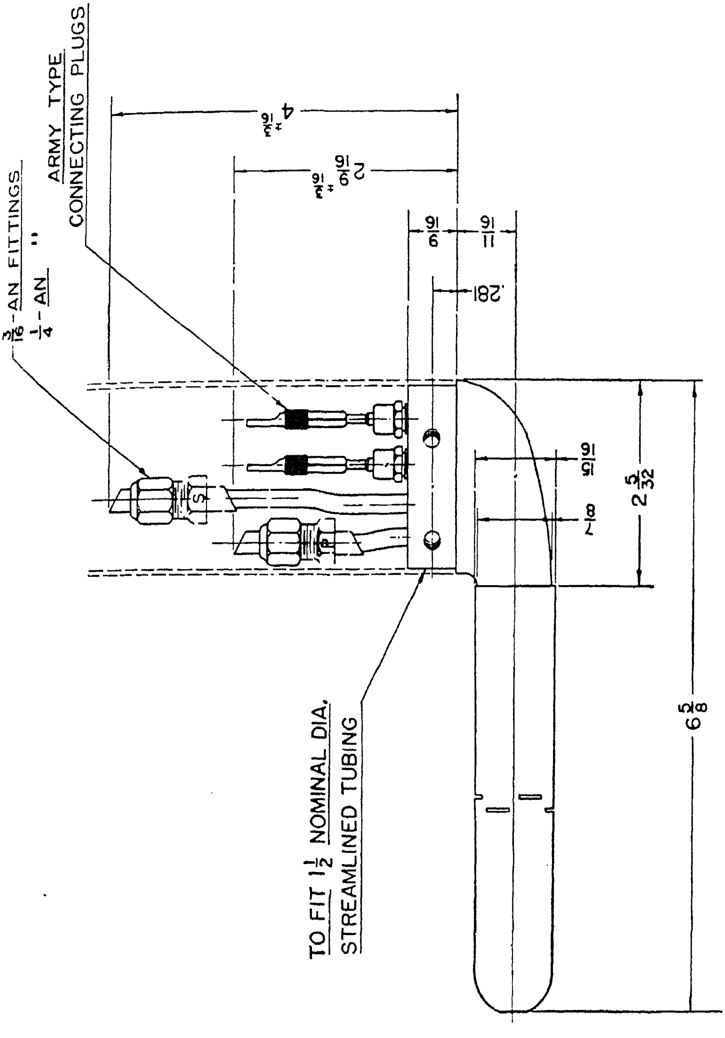


Figure 126. Pioneer Two-Wire Types 3202-3203-3218-3220 (Vertical Mounting)
(Pioneer Instrument Division of Bendix Aviation Corp.)

gently blowing in the *pitot line* at the pitot-static tube end of the line, while the instrument is observed. A short length of rubber tubing is an aid in performing this test and should be pinched off when a reading of about half scale is obtained. If the pointer does not remain stationary, there is a leak in the line being tested. If no reading is obtained, the line is obstructed. In either event, the defect should be remedied before connecting to the pitot-static tube. The above test should also be performed on the *static line* at the pitot tube end by *gently sucking* the line. All connections should be airtight for correct air-speed indications.

Warning: In the above leak test the pressures mentioned must be *very slowly* released. If there is a rate of climb indicator "teed" into the static pressure line, extreme caution must be exercised when applying suction to this line. The rate of climb indicator is very sensitive to *pressure changes* and should be closely observed during this suction leak test. Any sudden pressure change (increasing or decreasing) can seriously damage the rate of climb and render it inoperative.

The pitot static tube depends for satisfactory operation on its location in the airstream. Therefore it is highly advisable to investigate various practical mounting positions on the particular airplane and to select the one which provides correct air-speed indications. Usually it is mounted in a 1½" metal tube which protrudes forward of the leading edge of the wing near the wing tip or under the nose of a bi-motored or four-motored plane.

Maintenance

In the event of unsatisfactory operation of the air-speed indicator the following points should be checked before the instrument is removed from the airplane: water in the connecting lines, a damaged pitot tube, or a leak in the connecting lines. These will now be discussed.

WATER IN THE CONNECTING LINES. Disconnect both lines from the instruments, open the drain plugs, and blow out the lines with air.

Caution: If other instruments (altimeter and vertical speed indicator) are connected to the same static line, be sure they are also disconnected before applying pressure.

DAMAGED PITOT TUBE. Straighten the tube and make sure that it heads directly into the airstream. Neither the pitot opening nor the static slots should be deformed.

A LEAK IN THE CONNECTING LINES. Slip a rubber tube over the pitot tube far enough to cover the drain holes. Apply sufficient pressure to the line to cause an indication of approximately one-half of the range. The indication of the air-speed indicator should hold steady. If the hand returns to zero, check each connection for leak.

Slip a combination rubber tube and brass collar with a nipple over the pitot tube so that the collar is over the static holes. The bore of the collar should be slightly larger than the diameter of the tube. Apply a suction to the static holes so as to give an indication of about one-third of the range of the air-speed indicator, and pinch off the tube. If the pointer does not hold steady, examine all connections for leaks. After the connections are made tight, if the pointer still drops back at a faster rate than 1 m.p.h. per minute, the leak is probably around the cover glass and the instrument should be removed for repair.

CHAPTER 18

PIONEER TURN AND BANK INDICATOR

Operation

The turn indicator provides, with reference to the straight flight path, indication of the direction and rate, in degrees per minute, of a turn. The sensitive element of the turn indicator is a gyroscope operated at approximately 10,000 r.p.m. by an airstream impinging on its blades through a jet at the top rear of the instrument case. The source of the airstream is a pressure differential caused by application of suction to the instrument case, below the gyro wheel. The gyro rotates on ball bearings about the lateral axis in a frame which is pivoted on ball bearing supports about the longitudinal axis. Deviation of the aircraft from the straight flight path causes the gyro to precess to right or left about the longitudinal axis depending on the direction of turn. The precession force is approximately proportional to the angular rate of turn. The precession motion, which is opposed by an adjustable centralizing spring linked to the gyro frame is transmitted by levers to the pointer. Necessary damping of the precession motion is provided by a simple piston-and-cylinder device with an adjustable valve, the piston being linked to the gyro frame. A service feature of the turn indicator is the fact that calibration and damping adjustments are made externally by means of two screws, located on either side of the case. There are two standard centralizing springs, either one of which may be used to give a desired performance. One permits 5/16″ deflection of the turn pointer for a turn of 180° per minute. The other permits 5/32″ deflection for the same rate of turn.

The bank indicator is a ball sealed in a curved glass tube which is filled with a damping liquid. For a correct turn of the

Figure 127. Type 1700-1B

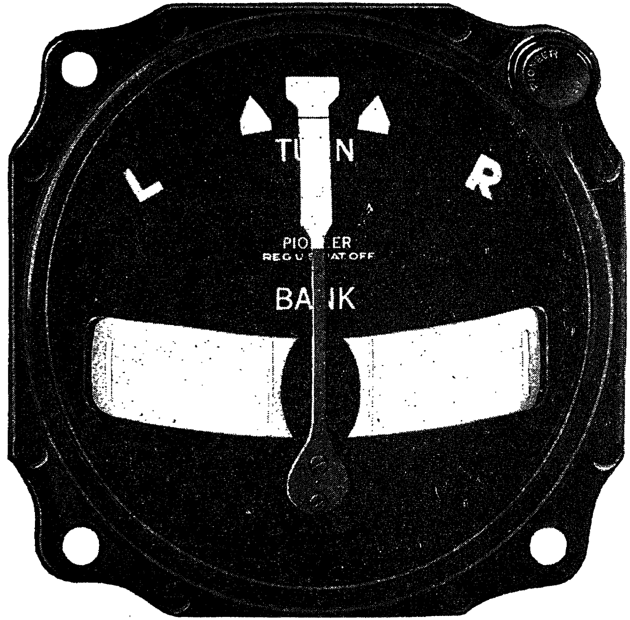


Figure 128. Type 1701-1A

(Pioneer Instrument Division of Bendix Aviation Corp.)

The turn and bank indicator is actually a combination of two flight instruments built conveniently into one instrument to facilitate coordination of turns and banks. It is the second member of the primary flight group.

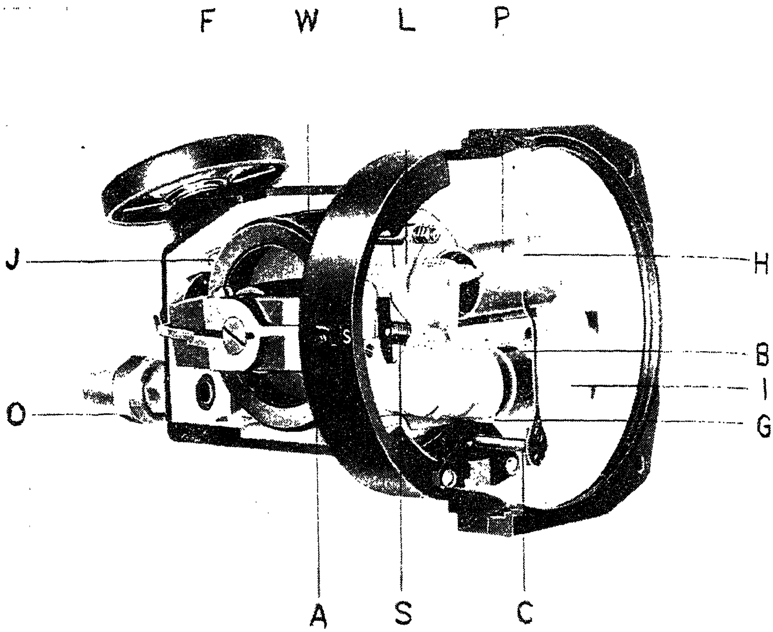


Figure 129. Showing a Detailed View of the Internal Construction of Pioneer Turn and Bank Indicator
(Pioneer Instrument Division of Bendix Aviation Corp.)

A—Case
B—Ball
C—Hand-staff assembly
F—Air intake filter
G—Inclinometer reference wire
H—Pointer
I—Inclinometer tube
J—Air intake jet
L—U arm
O—Connection for suction line (air outlet)
P—Piston and cylinder assembly
S—Centralizing spring
W—Gyro wheel

"ship" the ball, acted on by centrifugal force and gravity, will remain centered in the inclinometer tube. Combined with the turn indicator, it may be used to control the "ship" accurately during maneuvers.

Flying with the Turn and Bank Indicator

Our previous explanation dealt with the principle of operation of the turn indicator. Due to the importance of this instrument an additional diagram is shown (Figure 130) which illustrates the positions of the indicators under various flight con-

ditions. Directly under each illustration is shown the top view of a control stick and rudder bar with arrows showing which way these controls should be moved to bring the airplane back to straight and level flight. The positions of the turn indicator hand, which were previously explained, are shown in the upper part of each illustration. Just under center is the bank indicator which consists of a steel ball free to roll in a curved glass tube. The tube is also filled with liquid to prevent rapid oscillation of the ball. During straight flight the ball is acted on by gravity alone and therefore rolls to the lowest part of the tube which in level flight is at the center. During a turn, centrifugal force tends to make the ball roll toward the outside of the turn, while gravity tends to pull it to the lowest point. In a correct turn the resultant of these two forces is through the center of the tube, causing the ball to remain on center. Thus in either straight flight or turns, the ball indicates which wing is lower than it should be regardless of its angular relation to the horizontal. The first illustration shows the face of the instrument during straight and level flight. The turn indicator hand is on center and the ball of the bank indicator is at the center of the tube. The top center illustration covers a perfect left turn. In this case the hand shows that the plane is turning to the left. The center position of the ball indicates that neither wing is higher or lower than it should be. The wings are no longer parallel to the horizon but banked to the proper angle for the turn that the airplane is making. Right aileron and right rudder should be applied to straighten the ship. The next picture shows the right wing low. The plane is flying straight as shown by the turn indicator. The displacement of the ball to the right indicates that the right wing is low. Left aileron when applied will pick up the low wing.

The two bottom illustrations show a skidding and a slipping left turn. When the wings of a plane are not banked up enough in a turn, skidding results, which is similar to skidding in an automobile. The right wing, although banked up, is still lower than it should be. This is indicated by the displacement of the ball to the right. Left aileron will end the skid and bring the plane to the proper degree of bank for the turn, or right

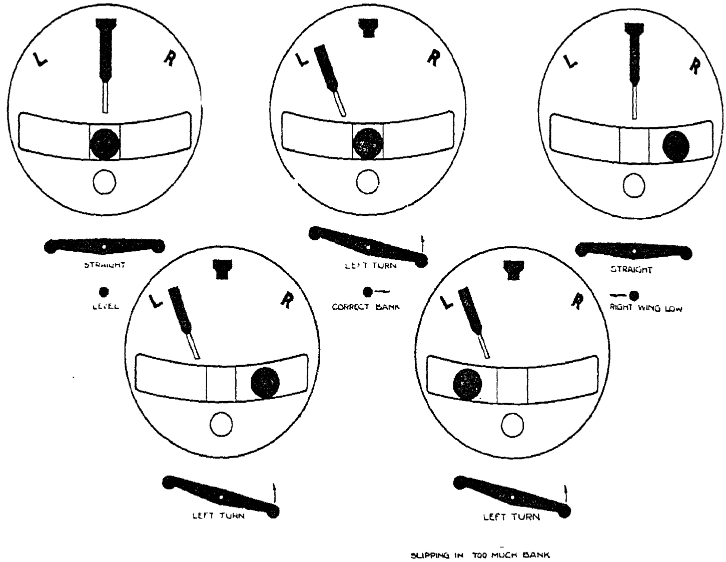


Figure 130. Turn and Bank Indicator Indications

rudder will stop the turn and therefore the skid. Should too much left aileron be applied, the plane will be overbanked and will side slip. In this case the left wing is too low and should be picked up by right aileron movement. Right rudder at the same time will straighten the ship out if we desire to return to straight and level flight.

Refer to Figure 128. The indices to the left and right of zero are known as 180° markers. In flight, if a pilot wishes to turn 180° in one minute (standard) he applies rudder until the hand coincides with the marker. By using the clock accurate turns can be made.

Test Apparatus

A motor-driven test apparatus is shown in Figure 131. The motor rotates the test rack at speeds of 36°, 180°, 360°, and 1,080° per minute when the handle in the front center of the instrument is placed in the proper slot. The rack is adaptable

with vacuum connections for testing five instruments together. A vacuum gauge, with face level with the top of the box, indicates vacuum readings. Air inlet and outlet valves are mounted at the left. An electrical switch for motor control is mounted at the right. Apparatus must be connected to a vacuum source.

Test Specifications

The following test may be made on the testing apparatus.

Turn Indicator.

STATIC BALANCE. With the instrument in any position and the gyro not spinning, the hand shall indicate zero within 0.015″.

DYNAMIC BALANCE. When the instrument is stationary in any position and the gyro operating under a suction of 2″ Hg, the hand shall indicate zero within 0.015″.

STARTING FRICTION. With the instrument in normal position, stationary and not being subject to vibration, a suction of not over 0.4″ of Hg shall cause the gyro to rotate.

SCALE ERROR. With the instrument in normal position and operating under a suction of 2″ Hg, a hand deflection in the proper direction shall be obtained for the following rates of turn:

STANDARD DEFLECTION

Rate of Turn	Deflection
36°/min.	1/16″ ±1/64″
180°/min.	5/16″ ±1/64″
360°/min.	½″ ±1/16″
1,080°/min.	1″ ± ⅛″

HAND OSCILLATION. With the instrument in normal position and operating under a suction of 2″ Hg there shall be no hand oscillation.

DAMPING TEST. With the instrument in normal position and with the gyro operating under a suction of 2″ Hg, rotate the instrument about the vertical axis at a rate to cause full

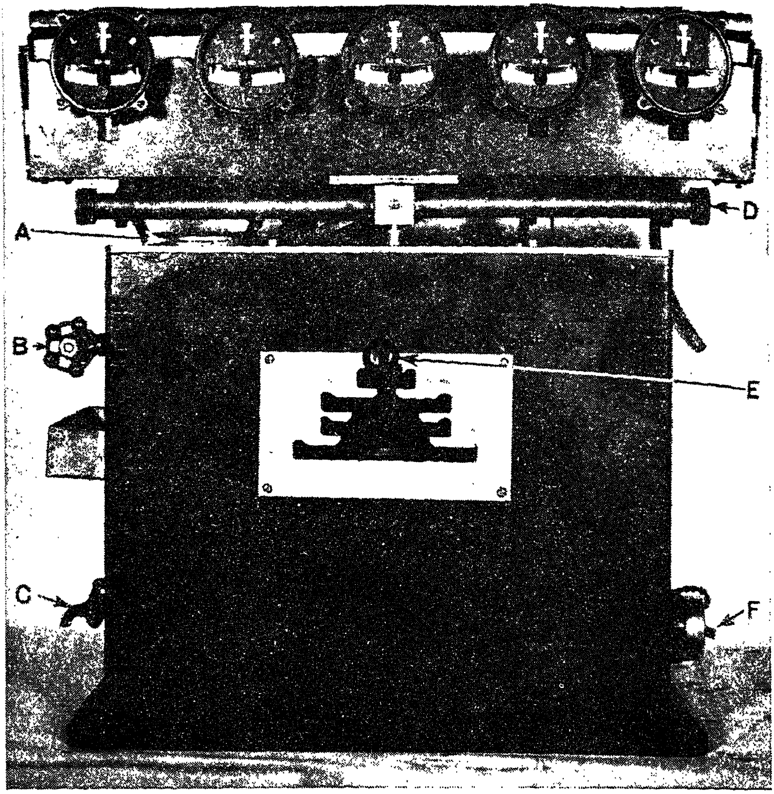


Figure 131. Turn and Bank Test Apparatus
(Pioneer Instrument Division of Bendix Aviation Corp.)

A—Vacuum Gauge
B—Air Inlet Regulator
C—Air Outlet
D—Vacuum Manifold
E—Rate of Turn Regulator
F—Electrical Switch

scale deflection of the hand. When the turning is suddenly stopped, the hand shall return to the zero mark, without crossing it.

Note: The gyro must run long enough to attain equilibrium speed. This is evidenced when two successive readings of the gyro taken 3 minutes apart are the same.

CASE LEAK TEST. In some suitable manner close the air intake. Attach a mercury manometer and a source of suction

of 10″ Hg to the pressure connection. With the source disconnected during a period of one minute, the difference between the mercury levels in the manometer shall not change by more than 0.2″.

Bank Indicator.

Zero Position. With the two lower mounting holes in the horizontal position and gentle tapping of the instrument, the black ball shall be at the zero marks within 1/32″.

Sensitivity. When the instrument is slowly tipped between 8° and 12° to either side of the vertical, the ball shall stop at the end of the tube within approximately 1/32″.

Damping Test. Maintaining the face of the dial in a vertical plane, the instrument shall be inclined 12° from normal. The instrument should then be suddenly inclined 24° so that the ball will roll to the opposite end of the tube. The time of roll of the ball from one end of the tube to within 1/32″ from the other end shall be not less than ½ second.

Friction Test. If the instrument is slowly tipped to either side of the vertical, the ball shall roll smoothly. The instrument can be lightly tapped.

Filling Test. The instrument shall be tipped so that all the air is trapped in the expansion chamber end of the tube. With the plane of the mounting lugs of the instrument in a vertical plane and with the line joining the centers of the two lower mounting holes in a horizontal plane, no part of the air bubble shall be visible when the instrument is viewed from a point 12″ directly in front of the zero mark on the bank indicator.

Installation

As the turn and bank indicator is the most important flight control instrument, it should be located on the instrument panel in the direct and unobstructed view of the pilot. It should preferably be in the center of the primary flight group between the air-speed and the rate of climb instruments.

The turn and bank indicator should be so mounted that, when the airplane is in level flight position, the dial of the instrument is vertical and the ball of the bank indicator is centered in the tube.

Complete panel drilling and cutout information for both the Type 1700 and 1701 instruments is given in Figures 133 and 134. These figures show the outline dimensions and the location of the pressure and electrical fittings for both the ring-lighted and unlighted type of instrument.

Ringlighted instruments (Figure 133) are equipped with a small 2-wire disconnect plug fitted with a ¼″ swedged type conduit fitting. The plug base contains a resistor that limits the current in the 3-volt bulb to 0.2 ampere when 12 volts are applied to the plug terminals. Thus the plug terminals should be connected in parallel with other instrument lights to the 12-volt circuit.

The vacuum line connection, as shown in Figure 133, can be made either at the back of the instrument or at the bottom. One-quarter inch solder fittings are supplied as standard.

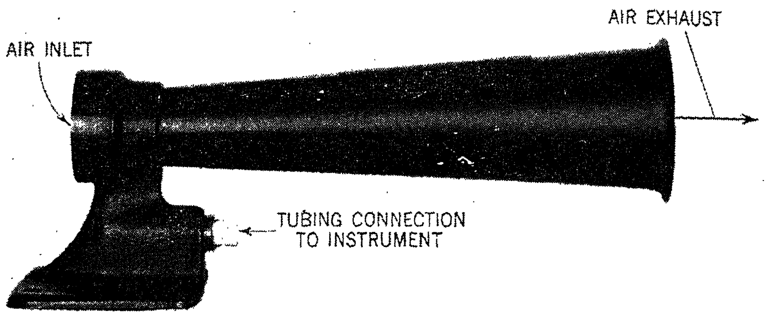


Figure 132. Pioneer Venturi Tube Type 748-900
(Pioneer Instrument Division of Bendix Aviation Corp.)

The vacuum supply is generally obtained from one of two sources. The recommended source is an engine-driven vacuum pump with an automatic pressure regulator that will maintain the pressure at 2″ (± 10%) of mercury less than atmospheric. An alternate supply is a venturi mounted in the slipstream. The

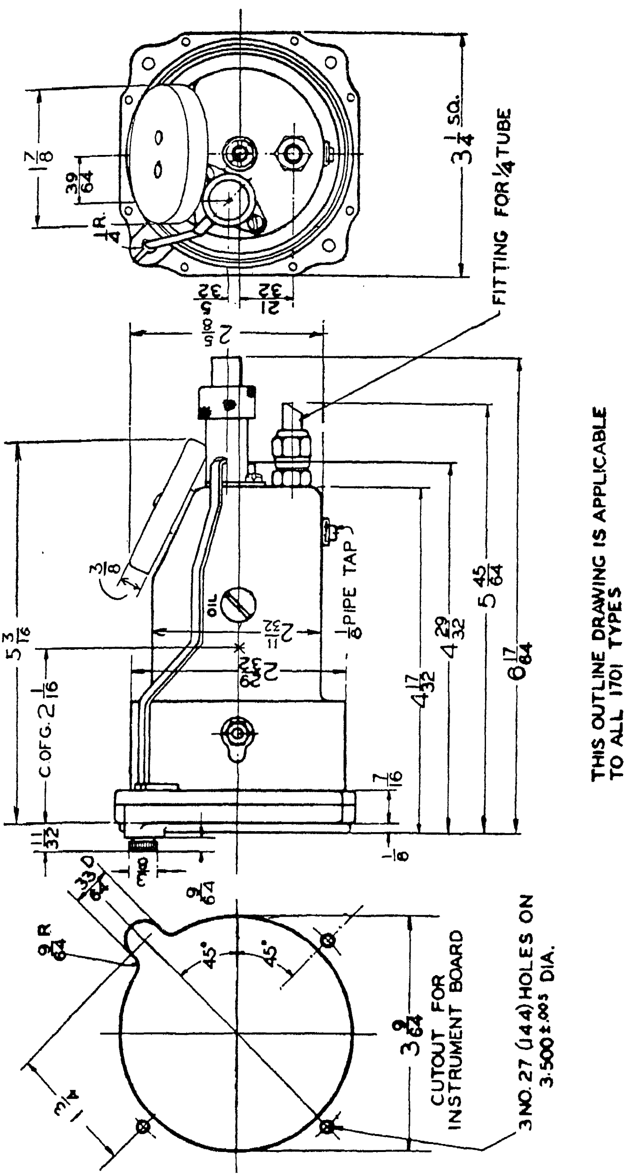


Figure 133. Pioneer Type 1701 Installation Dimensions
(Pioneer Instrument Division of Bendix Aviation Corp.)

Pioneer Type 74B-900, shown in Figure 132, designed for this purpose. This unit should be mounted in the slipstream with the indicating arrow pointed in the direction of flight. The venturi is to be connected to the turn and bank indicator with ¼″ tubing. It is imperative that the friction loss of head in this line be very small. Hence the line should be as short as possible and all bends must be smooth and of a radius not less than 3″. After installation the vacuum at the instrument must be checked with a suction gauge and regulator or check valves adjusted to give a vacuum at that point of 2″ of mercury $\pm 10\%$ (under cruising conditions).

To insure smooth operation and long life in the turn and bank indicator a vibration absorbing mount is recommended. While the instruments are designed to withstand 0.020″ total motion of vibration, best performance and longest trouble free life will be obtained at a total vibrational motion of 0.010″ or less.

Maintenance

Tabulated below are possible troubles and probable causes.

Trouble	Probable Cause
(a) Pointer oscillation.	Fork assembly is spread. Foreign matter in gyro bearings. Pitted gyro bearings. Wearing of damping assembly parts.
(b) Pointer does not return to zero.	Foreign matter in damping assembly. Worn centralizing spring stud.
(c) Pointer returns to same point but not to zero. Or left and right pointer readings are consistent but unequal.	Gyro and gimbal frame assembly out of balance.
(d) Unequal calibration to left and right.	Improperly formed centralizing spring. Foreign matter in damping assembly. Foreign matter in gimbal frame bearings. Pitted gimbal frame bearings.
(e) Stickiness.	Pointer rubbing on glass or inclinometer.

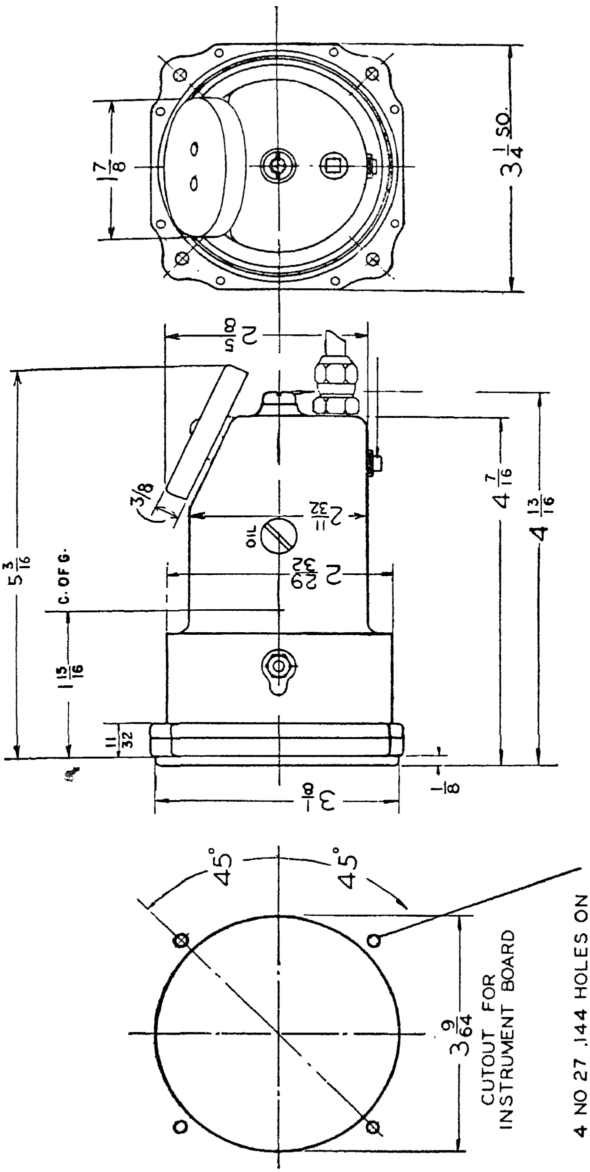
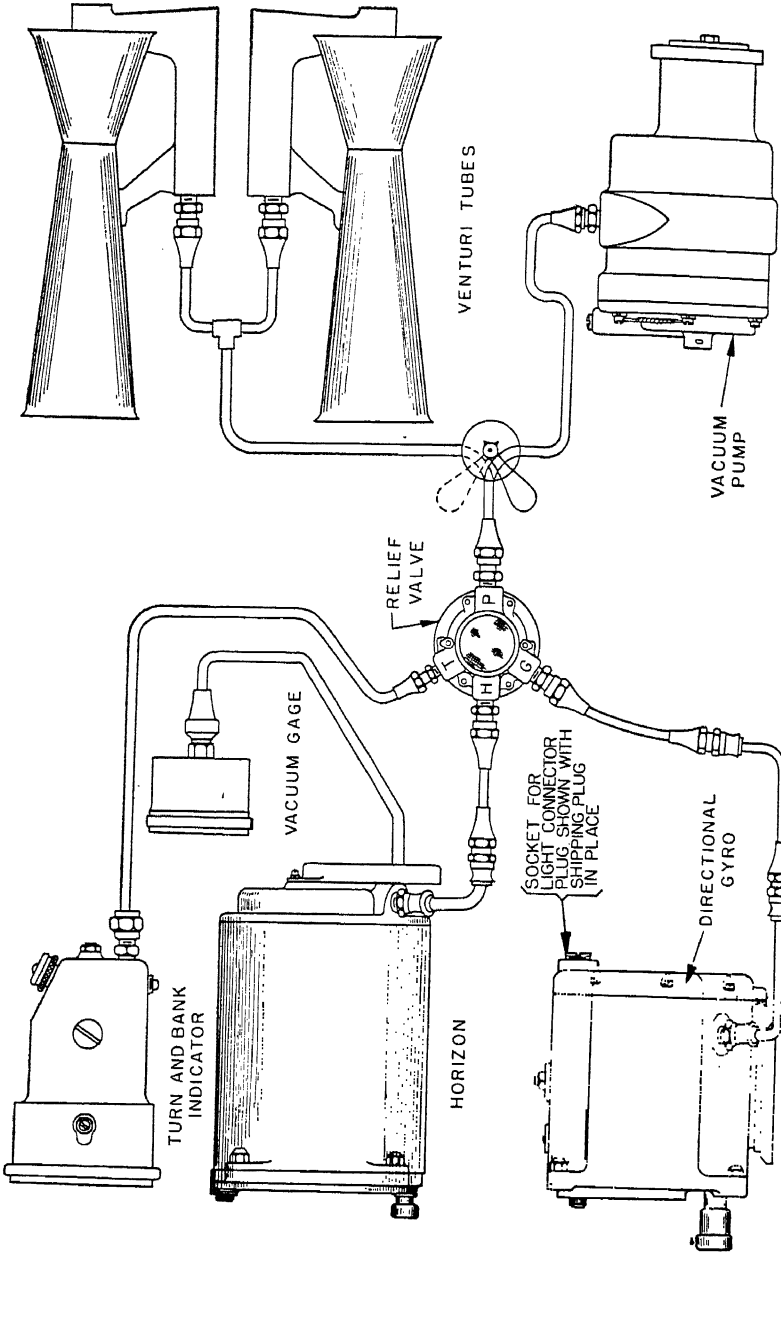


Figure 134. Pioneer Type 1700 Installation Dimensions
This outline drawing applicable to all 1700 Types
(Pioneer Instrument Division of Bendix Aviation Corp.)


VENTURI TUBES
VACUUM PUMP
RELIEF VALVE
P
T
G
H
VACUUM GAGE
SOCKET FOR LIGHT CONNECTOR PLUG SHOWN WITH SHIPPING PLUG IN PLACE
DIRECTIONAL GYRO
TURN AND BANK INDICATOR
HORIZON

CHAPTER 19

RATE OF CLIMB-VERTICAL SPEED INDICATOR

The rate of climb-vertical speed indicator is the third member of the primary flight group of instruments consisting of the air-speed indicator, turn and bank indicator, and the rate of climb-vertical speed indicator as shown below in Figure 138.

This instrument is used as a measure of the rate at which the airplane is changing its pressure altitude. It is essentially a level flight instrument but also serves an extremely important function when used to govern the throttle setting in blind flight (the air-speed indicator being used to govern the elevator setting). It will function accurately under all conditions of temperature and altitude encountered in airplane operation.

Flying with the Rate of Climb-Vertical Speed Indicator

The altimeter is usually mounted in close proximity to the rate of climb-vertical speed indicator. Any desired change in pressure altitude may be gained by nosing the airplane up or down and leveling off at the desired altitude, the rate of climb-vertical speed indicator giving the rate in feet per minute at which the ascent or descent was made. Usually about 350 feet per minute is considered about the proper rate of ascent or descent for the convenience of passengers aboard the plane. It should be remembered when you level off and the altimeter reading is steady, that the rate of climb-vertical speed indicator may still continue to indicate either the ascent or descent. However, if the airplane is held in the level attitude, as shown by the altimeter, for about 7 seconds the hand of the rate of climb-vertical speed indicator will assume a zero reading. This is due to the "lag" in the instrument. As shown in the following illustrations the instrument dials may be calibrated differently. A 90° hand travel on one type will indicate 500 feet per minute

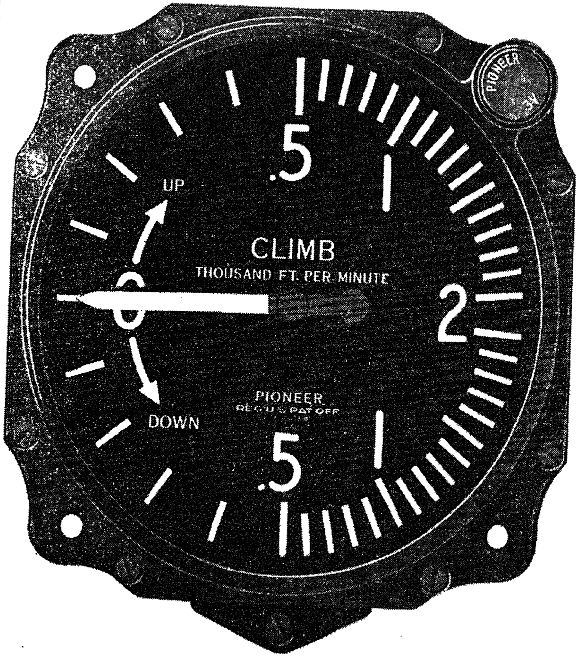


Figure 136. Pioneer Rate of Climb Indicator Type 1601

Figure 137. Pioneer Rate of Climb Indicator Type 1610

(Pioneer Instrument Division of Bendix Aviation Corp.)

ascent or descent, while on another type a 90° hand movement may indicate 1,000 feet per minute. The pilot should scrutinize the readings and various calibrations of all instruments before a flight in an unfamiliar airplane.

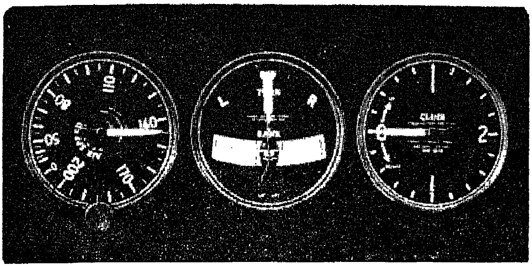


Figure 138. Primary Flight Group
(Pioneer Instrument Division of Bendix Aviation Corp.)

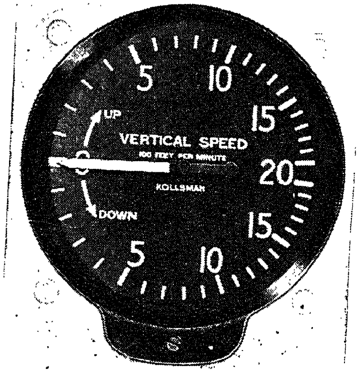
Operation of Kollsman Type 612K

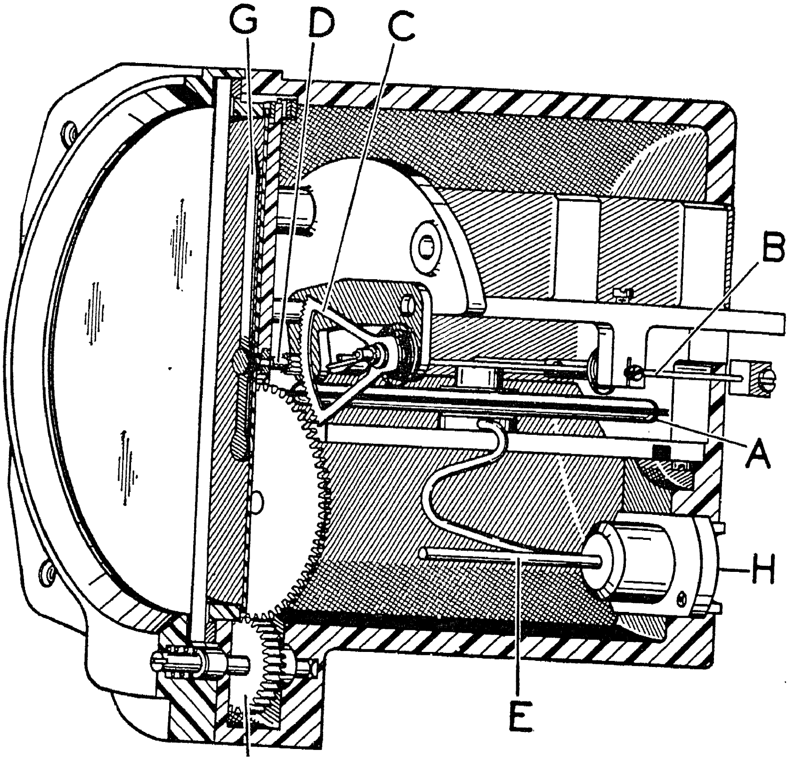
The indicator consists primarily of an airtight diaphragm (A) assembly and a mechanism for multiplying its deflection. The multiplying mechanism consists of a rocking-shaft assembly (B), a sector assembly (C) and a hand-staff pinion (D). The capillary tube (E) retards the equalization of pressures. A gear train (F) operates a cam for resetting the pointer (G) to zero. Connection to the static line (H) of the pitot tube is made at the rear of the case.

Density and pressure of the air decrease with altitude. The atmospheric pressure may be likened to layer upon layer of air and each layer having a lesser pressure as altitude is gained. The reverse is true during a descent, each layer having a greater air pressure.

The instrument being connected to the static line of the pitot tube receives the true static pressures encountered in flight.

Referring to Figure 140, air will enter at the static line connections. The capillary tube is a leak device which somewhat restricts the flow of air. In level flight the pressure on the outside of the diaphragm will equal that on the inside of the diaphragm and the pointer will indicate zero. If the airplane is put in a climbing attitude a lesser pressure will exist on the





(Kolls:

Cut-Away View
ı Type 612K
.)

inside of the diaphragm while the greater pressure on the outside of the diaphragm will compress the diaphragm. The pointer will move clockwise indicating a climb.

As soon as the airplane is returned to a level flight attitude, the greater pressure on the outside of the diaphragm will leak through the capillary tube, into the diaphragm, the pressures will be equal and the pointer will return to zero. The opposite is true when descending.

Directions for Shop Testing

Two stands are used for testing and adjusting the mechanism of the rate of climb-vertical speed indicator for balance range and calibration. The leak assembly is replaced by a plug and the mechanism is tested as a pressure instrument.

Millimeter Test Stand. The millimeter test stand is essentially a "U" tube partly filled with mineral seal oil. Flexible rubber tubing is run through a roller to apply pressure or suction to one side of the "U" tube and to the mechanism which is being tested. The other leg of the "U" tube is open. A movable scale, marked in millimeters, is used to measure the pressure head difference in level between the two columns of liquid.

Range and Balance Stand. The range and balance stand provides a means of holding the instrument mechanism for test and adjustment while under light vibration. The mechanism under test is mounted on the rotatable ring in the stand. Four pins aid in turning the ring to any angle to test the balance of the mechanism. A vibrator attached to the ring eliminates any friction in the mechanism.

The upper part of the stand may be rotated as a unit to facilitate adjustment on the mechanism. The test case and test dial are standard parts cut away to provide access to the mechanism. The outer edge of the dial is also cut away to give sufficient clearance when removing mechanism from the case.

Directions for Shop Test (Pioneer Type). Assemble the instrument mechanism with a test dial and pointer into the test

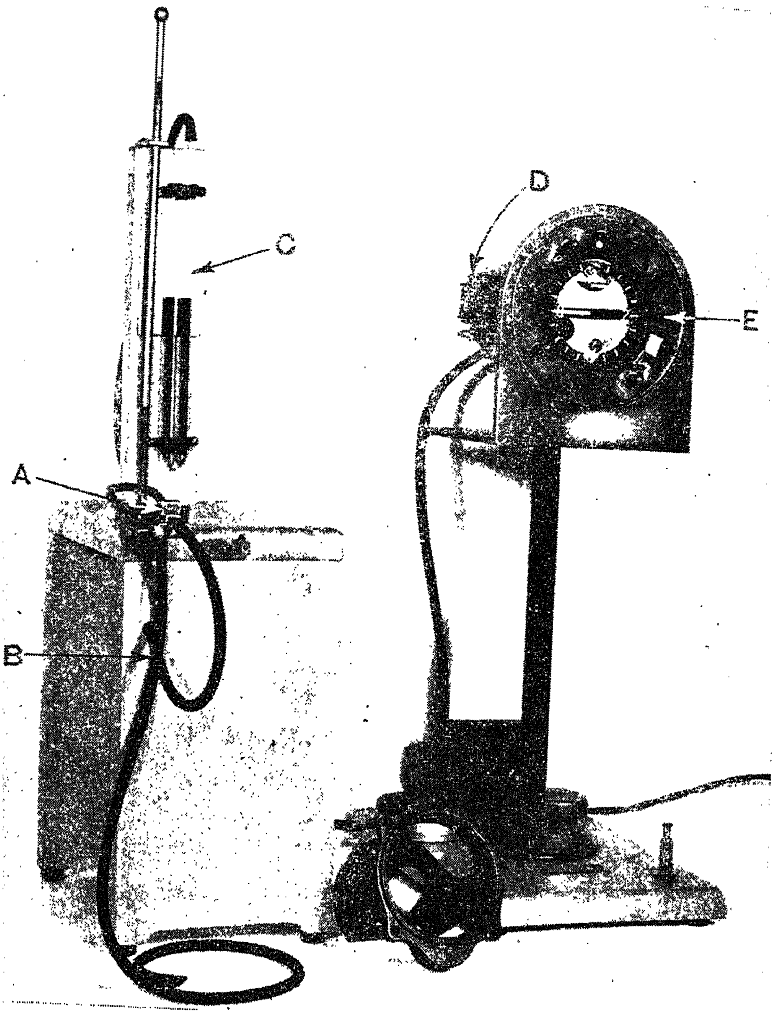


Figure 141. Millimeter Test Stand Figure 142. Range and Balance Stand

Pioneer Rate of Climb Indicator-Test Apparatus

(Pioneer Instrument Division of Bendix Aviation Corp.)

A—Roller
B—Rubber Tubing
Movable Millimeter Scale
D—Vibrator
E—Rotatable Ring

case. Remove the leak assembly and plug the opening so that pressure may be applied to the diaphragm through the static connection in the back of the case. Mount the instrument in the range and balance stand.

Test the balance of the mechanism by rotating the instrument to each 90° position and noting the variation of the pointer from zero. Correct the balance by moving the counter weight in the mechanism. Vibrate the instrument during all tests.

The instrument is tested for range and calibration in the normal operating position. Pressure is applied through the rubber tubing from the roller on the millimeter test stand. Set the pointer exactly on zero. The vibrator should be on throughout the following test.

Apply pressure to bring the pointer of the instrument up to the desired reading. Adjust the scale on the millimeter test stand to bring the long zero line (in the center of the scale) to the bottom of the meniscus of the right leg, the meniscus being the curved surface of the liquid in the tube. The height of the meniscus of the left leg above the zero line indicates the pressure in millimeters of mineral seal oil. Since measurements of pressure to one-tenth of a millimeter must be made, the bottom of the side will aid in making the meniscus appear very sharp. The millimeter test stand must be level in these tests.

After any adjustment on the instrument the pointer should be reset by lifting it from the pinion staff and replacing exactly on zero. The position of the zero adjustment screw should not be changed during calibration.

The final steps include the assembly of the leak device into the mechanism, and the testing of the complete instrument in a pressure chamber. For this final calibration check, a mercurial test barometer is required in conjunction with the pressure chamber.

Calibrating Bottle (Figure 143). Instruments of the latest type not requiring an external reservoir may be tested while still in the cut-away test case if a bottle equal to the effective volume of the case is connected to the static connection. Recommended

for this test is Pioneer calibration bottle which is supplied complete with the cut-away case and dial used also in the various other phases of calibration. When using the calibration bottle the up and down indications will be reversed.

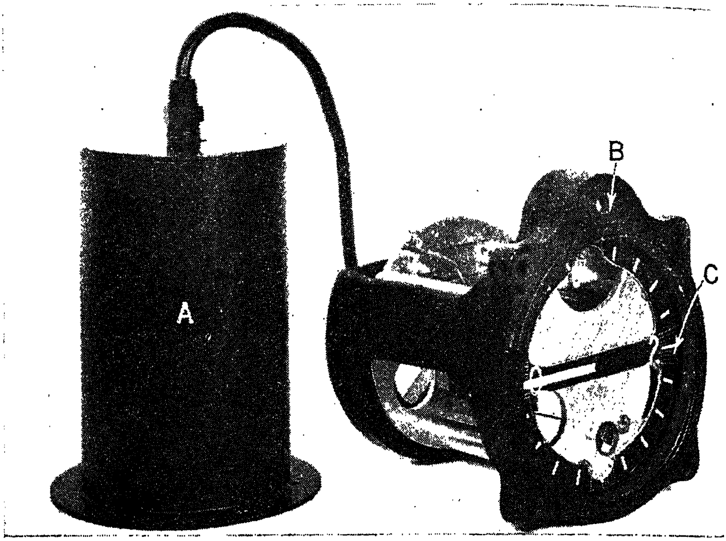


Figure 143. Pioneer Calibration Bottle, Cut-Away Case and Dial
(Pioneer Instrument Division of Bendix Aviation Corp.)
A—Calibration Bottle B—Cut-Away Case C—Dial

A single instrument test chamber is particularly adaptable for calibrating service altimeters, sensitive altimeters and rate of climb indicators. It is used in conjunction with a standard mercurial test barometer.

A source of suction completes the requirements for operation and can be obtained from a motor-driven vacuum pump. The suction line is connected to the fitting provided in back of the chamber. There are two hand-operated needle valves, one of which controls the suction and the other the air bleed from the outside pressure. The barometer is connected to the air chamber through a rubber tubing.

A vibrator mounted on the rear of the stand is controlled by a push button and switch on the front and operates on low

voltage through a transformer installed on the stand. The vibrator is used to uniformly take out possible friction errors.

If necessary, center the pointer by means of the zero adjustment. Tap the case gently as the adjustment is very sensitive. Place the indicator in the chamber. Evacuate until the barometer

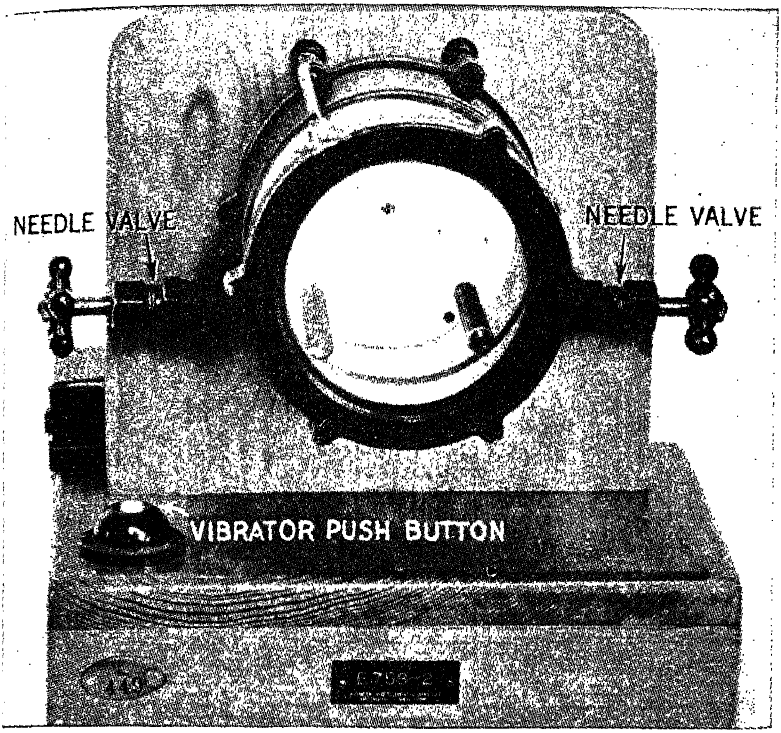


Figure 144. Pioneer Single-Instrument Test Vacuum Chamber
(Pioneer Instrument Division of Bendix Aviation Corp.)

reads, for instance, 5,000 feet. Stop the vacuum pump and open release valve until climb indicator hand shows a uniform rate of descent, i.e., 1,000 feet per minute. Time the interval that it takes for the barometer to move through a 1,000-foot increment.

By dividing the indicator drop in feet by the time, the true rate of descent can be arrived at, and compared with the rate

indicated on the instrument. Similarly for "climb" readings, adjust the pressure valve until the indicator shows a uniform rate of ascent, and holding this constant time the interval as before to arrive at a true rate of ascent. This check may be made for as many different rates on the instrument scale as desired.

Test Specifications

The following test specifications apply to Pioneer Type 1601 only. For all other types and makes the manufacturer's test manuals should be consulted.

Unless otherwise stated, all tests shall be made at room temperature (approximately +20° C.) and atmospheric pressure (approximately 29.92 Hg). When tests differ materially from above conditions, proper allowance shall be made for the difference from specified conditions. Except when otherwise specified the instrument shall be tested in normal flight position and shall be adequately vibrated before a test reading is taken.

The following tests shall be performed.

(a)

Standard Altitude Interval	Indicated Rate	Tolerance	
Feet	Ft./min.	Up	Down
2,000 to 4,000	400	35	35
	1,000	75	75
	1,800	150	150
15,000 to 17,000	400	70	70
28,000 to 30,000	400	70	70

(b) Lag. The static pressure connection of the instrument shall be suitably connected to a water manometer and a source of suction and pressure. A suction shall be carefully applied to the static connection of the case which will give an approximate pointer deflection of 1,000 ft./min. when released. The suction shall then be released and the pointer allowed to return to zero. A stop watch shall be started when the hand reaches 500 ft./min. and stopped when the hand passes 100 ft./min. This procedure shall be repeated except with an equivalent pressure applied to

the static pressure connection of the case. The time on each test shall be between 12.5 and 9.5 seconds. During the lag test the hand shall move smoothly without excess friction and without oscillation through an amplitude in excess of 200 ft./min.

(c) POSITION ERROR. The reading taken while the instrument is held in any desired position and while it is being tapped shall not differ from its preceding reading when held in any other position by more than 20 ft./min.

(d) ZERO SETTING. The zero setting knob shall be capable of moving the hand through a range of 200 ft./min.

(e) CASE LEAK. The connection on the back of the case shall be suitably connected to a mercury manometer and a source of suction. A suction of 15″ of mercury shall be applied to the instrument case. During a period of 10 seconds, the pressure as indicated by the mercury manometer shall not change by more than 0.4″. This procedure shall be repeated for a pressure of 10″ of mercury gradually applied.

(f) INSULATION BREAKDOWN. On all ringlighted instruments with the lamp removed 550 volts at commercial frequency for a period of one minute shall cause no breakdown in insulation.

Installation

The rate of climb-vertical speed indicator is usually mounted in a horizontal grouping with the air-speed and the turn and bank indicator. All three should be mounted high on the panel in the unobstructed view of the pilot.

To mount any of these instruments a hole 3 9/64″ in diameter is cut in the panel. Four mounting holes must be drilled, in the panel, equally spaced on a 3½″ diameter circle concentric with the cut-out.

The instrument must be connected to the static line of a well-installed pitot tube if satisfactory operation is to be obtained. All connections should be made with metal tubing with a minimum diameter of 3/16″.

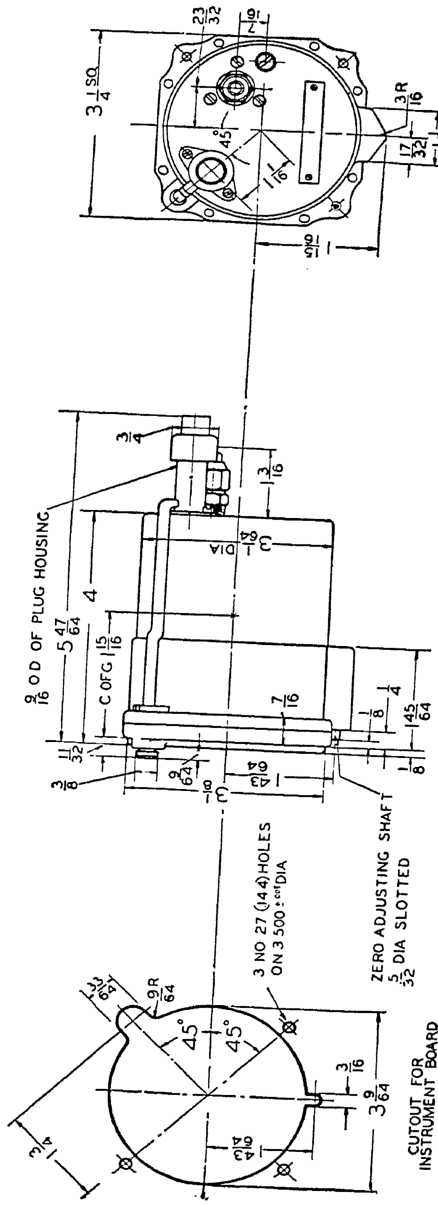


Figure 145. Pioneer Type 1601 Installation Dimensions
(Pioneer Instrument Division of Bendix Aviation Corp.)

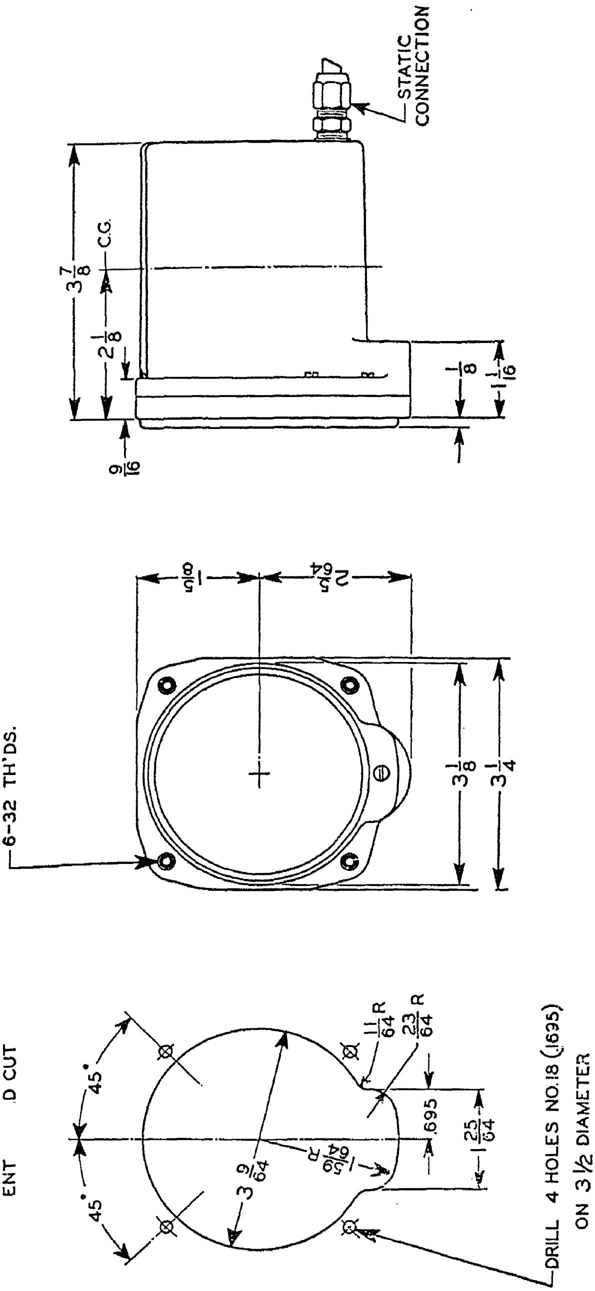


Figure 146. Kollsman Type 612K
(Kollsman Instrument Division of Square D Co.)

In order to assure long life and trouble-free operation, these instruments should be mounted on a panel that is adequately protected from vibration. The total amplitude of vibration should not exceed a 0.006″ at any time.

Maintenance

Possible troubles with their probable causes are tabulated below:

Trouble	Probable Cause
(a) Pointer is off zero.	Mechanism shift.
(b) Pointer is off zero and cannot be brought back by zero adjusting	Broken pivot.
(c) Instrument indicates less than actual climb.	Case leak.
(d) Friction.	Dirty pivots and jewels. Broken jewels. Improper clearances.
(e) Pointer sticks.	Pointer rubs against glass, dial or dial screws. Dirt in sector or pinion teeth.

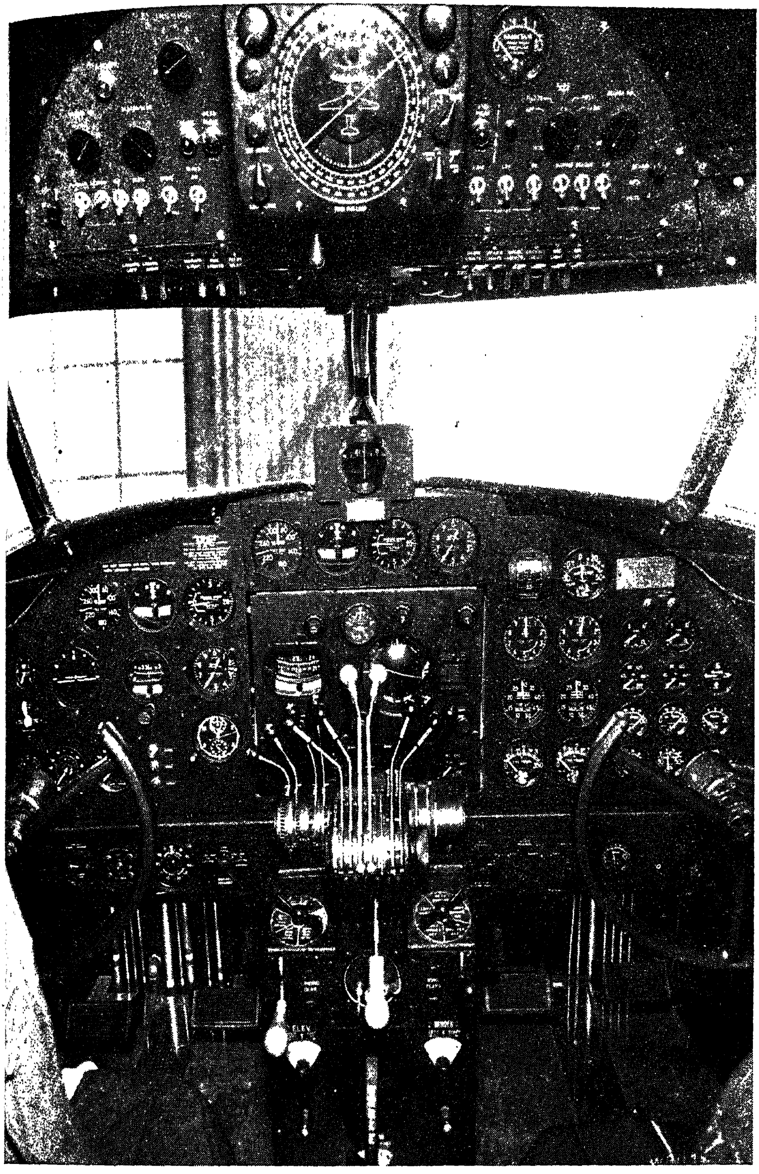


Figure 147. Instrument Panel

(Lockheed Aircraft Corp.)

A well-balanced Lockheed panel is shown here. At the left directly in front of the pilot are the flight instruments. At the right are the engine instruments for the observation of the co-pilot. In the center is located the Sperry Automatic Pilot.

CHAPTER 20

ALTIMETER

The altimeter is an instrument which measures the atmospheric pressure and translates it into feet of altitude. If the atmospheric pressure were always constant at a given altitude the altimeter could then be used to measure altitude without corrections for variations of pressure. But such is never the true case. The atmospheric pressure varies several times a day for any given locality and as the pressure varies so varies the reading of the altimeter.

As an example, let us assume an airplane is on the ground and the pointer indicates zero. It will be noted that the instrument shop barometer reads 29.92″ of Hg (mercury), which is standard sea level pressure. Later in the day a decreased atmospheric pressure causes the barometer to read 29.38″ of Hg. Upon observing the altimeter in the airplane it will be seen that the altimeter pointer indicates 500 feet of altitude. Actually the airplane has not left the ground. With this in mind it is understandable that a sensitive altimeter is nothing more than a sensitive barometer which reacts to the slightest atmospheric change.

Temperature changes also affect the altimeter and must be taken into consideration. A decrease in temperature from the standard value will give a higher indicated altitude and an increase in temperature from standard will give a lower indicated altitude.

Therefore it follows, that any change in atmospheric pressure or temperature from the standard values will cause the reading of the altimeter to be in error.

Table I shows the standard atmospheric pressure in inches of Hg, millimeters of Hg, and the standard and mean temperature.

Figure 148. Pioneer Sensitive Altimeter Type 1523-2B

Figure 149. Pioneer Sensitive Altimeter Type 1501-1A

Direct Reading Barometric Indication

(Pioneer Instrument Division of Bendix Aviation Corp.)

TABLE I

Altitude, feet	Pressure in Hg	mm. Hg	Temperature, C.	Mean Temperature, C
−1,000	31.02	787.9	17.0	16.0
− 500	30.47	773.8	16.0	15.5
0	29.921	760.0	15.0	15.0
500	29.38	746.4	14.0	14.5
1,000	28.86	732.9	13.0	14.0
1,500	28.33	719.7	12.0	13.5
2,000	27.82	706.6	11.0	13.0
2,500	27.31	693.8	10.0	12.5
3,000	26.81	681.1	9.1	12.0
3,500	26.32	668.6	8.1	11.5
4,000	25.84	656.3	7.1	11.0
4,500	25.36	644.2	6.1	10.5
5,000	24.89	632.3	5.1	10.0
5,500	24.43	620.6	4.1	9.5
6,000	23.98	609.0	3.1	9.0
6,500	23.53	597.6	2.1	8.5
7,000	23.09	586.4	1.1	8.0
7,500	22.65	575.3	0.1	7.5
8,000	22.22	564.4	− 0.8	7.0
8,500	21.80	553.7	− 1.8	6.5
9,000	21.38	543.2	− 2.8	6.0
9,500	20.98	532.8	− 3.8	5.5
10,000	20.58	522.6	− 4.8	5.0
10,500	20.18	512.5	− 5.8	4.5
11,000	19.79	502.6	− 6.8	4.0
11,500	19.40	492.8	− 7.8	3.5
12,000	19.03	483.3	− 8.8	2.9
12,500	18.65	473.8	− 9.8	2.4
13,000	18.29	464.5	−10.8	1.9
13,500	17.93	455.4	−11.7	1.4
14,000	17.57	446.4	−12.7	0.9
14,500	17.22	437.5	−13.7	0.4
15,000	16.88	428.8	−14.7	− 0.1
15,500	16.54	420.2	−15.7	− 0.6
16,000	16.21	411.8	−16.7	− 1.2
16,500	15.89	403.5	−17.7	− 1.7
17,000	15.56	395.3	−18.7	− 2.2
17,500	15.25	387.3	−19.7	− 2.7
18,000	14.94	379.4	−20.7	− 3.2
18,500	14.63	371.7	−21.7	− 3.7
19,000	14.33	364.0	−22.6	− 4.3
19,500	14.04	356.5	−23.6	− 4.8

Altitude, feet	Pressure in Hg	n. Hg	Temperature, C.	Mean Temperature, C.
20,000	13.75	349.1	−24.6	− 5.3
20,500	13.46	341.9	−25.6	− 5.8
21,000	13.18	334.7	−26.6	− 6.3
21,500	12.90	327.7	−27.6	− 6.9
22,000	12.63	320.8	−28.6	− 7.4
22,500	12.36	314.1	−29.6	− 7.9
23,000	12.10	307.4	−30.6	− 8.4
23,500	11.84	300.9	−31.6	− 9.0
24,000	11.59	294.4	−32.5	− 9.5
24,500	11.34	288.1	−33.5	−10.0
25,000	11.10	281.9	−34.5	−10.5
25,500	10.86	275.8	−35.5	−11.1
26,000	10.62	269.8	−36.5	−11.6
26,500	10.39	263.9	−37.5	−12.1
27,000	10.16	258.1	−38.5	−12.7
27,500	9.94	252.5	−39.5	−13.2
28,000	9.72	246.9	−40.5	−13.7
28,500	9.50	241.4	−41.5	−14.3
29,000	9.29	236.0	−42.5	−14.8
29,500	9.08	230.7	−43.4	−15.3
30,000	8.88	225.6	−44.4	−15.9
30,500	8.68	220.5	−45.4	−16.4
31,000	8.48	215.5	−46.4	−16.9
31,500	8.29	210.6	−47.4	−17.5
32,000	8.10	205.8	−48.4	−18.0
32,500	7.91	201.0	−49.4	−18.6
33,000	7.73	196.4	−50.4	−19.1
33,500	7.55	191.8	−51.4	−19.6
34,000	7.38	187.4	−52.4	−20.2
34,500	7.20	183.0	−53.4	−20.7
35,000	7.04	178.7	−54.3	−21.3
35,332	6.93	175.9	−55.0	−21.6
35,500	6.87	174.5	−55.0	−21.8
36,000	6.71	170.4	−55.0	−22.3
36,500	6.55	166.4	−55.0	−22.8
37,000	6.39	162.4	−55.0	−23.3
37,500	6.24	158.6	−55.0	−23.8
38,000	6.10	154.9	−55.0	−24.3
38,500	5.95	151.2	−55.0	−24.8
39,000	5.81	147.6	−55.0	−25.2
39,500	5.68	144.1	−55.0	−25.6
40,000	5.54	140.7	−55.0	−26.0

Operation of Pioneer Altimeters

While the mechanical construction of Pioneer and Kollsman altimeters differs, the basic operating principle is the same.

Referring to Figure 149, in order that the instrument may be read easily and with a minimum of human error the barometric setting is indicated on an odometer type of counter which is visible through a cut-out in the lower portion of the dial. The pointer indicates 110 feet altitude. By rotating the barometric counter knob the long hand may be reset to zero. The 29.92″ of Hg reading will then be changed to correspond to the actual barometric pressure.

The long hand makes one revolution for each 1,000 feet altitude and the short hand one revolution for each 10,000 feet altitude.

Refer to Figure 148. The long and intermediate hands indicate the same as the hands in Figure 149. The small hand is incorporated to indicate 10,000 feet increments which are indicated on the small circular dial.

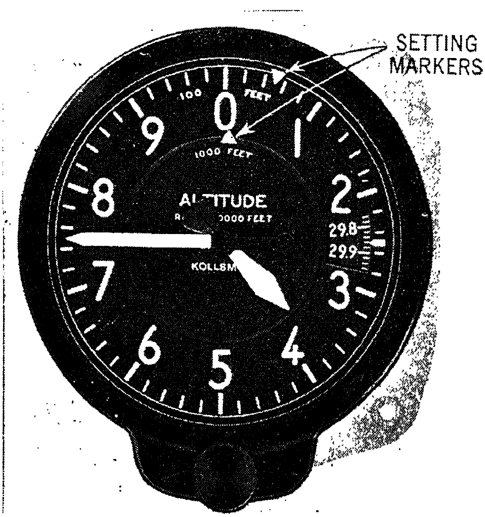


Figure 150. Kollsman Type 497K-01
(Kollsman Instrument Division of Square D Co.)
Showing setting markers in connection with barometric scale for setting at high altitude

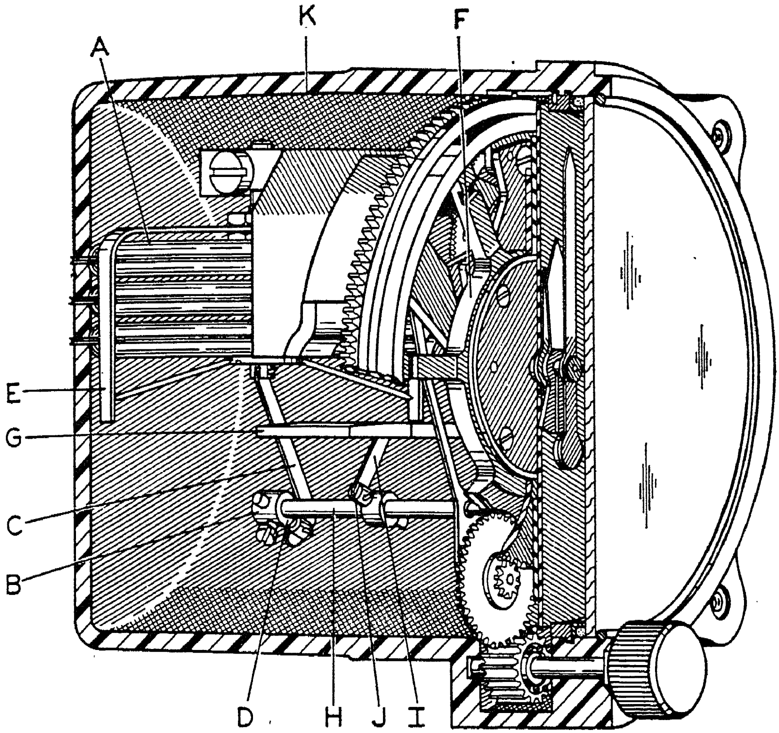


Figure 151. Schematic Drawing Kollsman Sensitive Type
(Kollsman Instrument Division of Square D Co.)

Operation of Kollsman Sensitive Type

The altimeter consists of an evacuated diaphragm assembly (A) and a mechanism for multiplying its deflection.

The mechanism is composed of a rocking-shaft assembly (B) with diaphragm link (C), calibration arm (D), a sector, multiplying gear train and hand-staff. A hairspring secured to a member of the gear train and anchored to the mechanism body removes backlash from the mechanism.

A temperature responsive element (E) is mounted on the diaphragm assembly. This element has been set to eliminate accurately errors in indication due to temperature variation of the indicator. It should not be altered.

The reducing gear train which operates the small pointer or pointers is contained in the top plate mechanism (F).

Static balance of the diaphragm and mechanism is maintained by balance assembly (G) which is connected to the rocking-shaft (H) by link (I) and balance adjusting arm (J).

The entire mechanism is housed in an airtight case (K) having an external fitting for connection to the static line.

The pressure exerted upon the surface of the diaphragm at zero altitude decreases with a decrease of atmospheric pressure which occurs with an increase of altitude. This will cause the diaphragm to expand. The rocking-shaft picks up the motion by means of its calibration arm and connecting link and in turn transmits the motion through the sector, gear train, and finally to the hand-staff pinion. The pointers indicate altitude in feet (meters).

Flying with the Altimeter

It is essential that the pilot know the construction of his altimeter. Some altimeters incorporate a temperature responsive element as shown in Figure 151, which eliminates temperature variations. Others do not. But whether or not the temperature errors are eliminated, the problem of atmospheric pressure changes is always present.

Two methods are used for landing. A system of operation that has gained popularity involves the setting of the barometric counter in units of altitude. With this system the reference level can be either sea level or the altitude of any station contacted by radio.

In using this system of barometric setting it is preferable for the station to have an altimeter with the same type of barometric indicator as the airplane. (See Figure 152.) If the sea level reference is to be used, the airport station altimeter is set at the known altitude of the airport and the barometric counter reading transmitted to the pilot, who then sets his altimeter to the same counter reading. Upon landing the altimeter will indicate the known altitude of the airport.

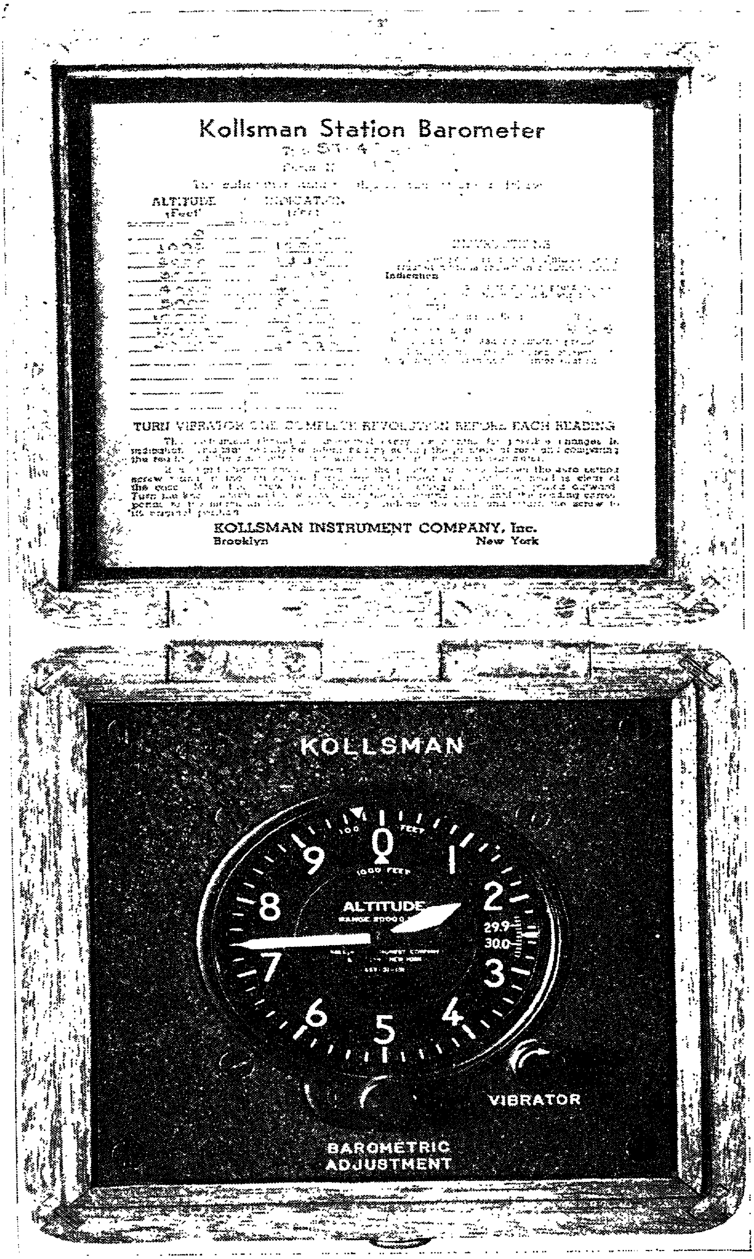


Figure 152. Kollsman Station Barometer (Altimeter Reading)
(Kollsman Instrument Division of Square D Co.)

If the airport surface is to be used as a reference level, the airport station altimeter is set to read zero altitude and the barometric counter reading transmitted to the pilot who then sets his altimeter to the same counter reading. Then when the airplane lands at this particular airport, its altimeter will read zero.

Flight Analyzer

Early in 1941, the Civil Aeronautics Board ruled that all transport planes operated in the United States should be equipped with automatic flight analyzers or barographs to write a permanent record of each flight such as that given in Figure 153.

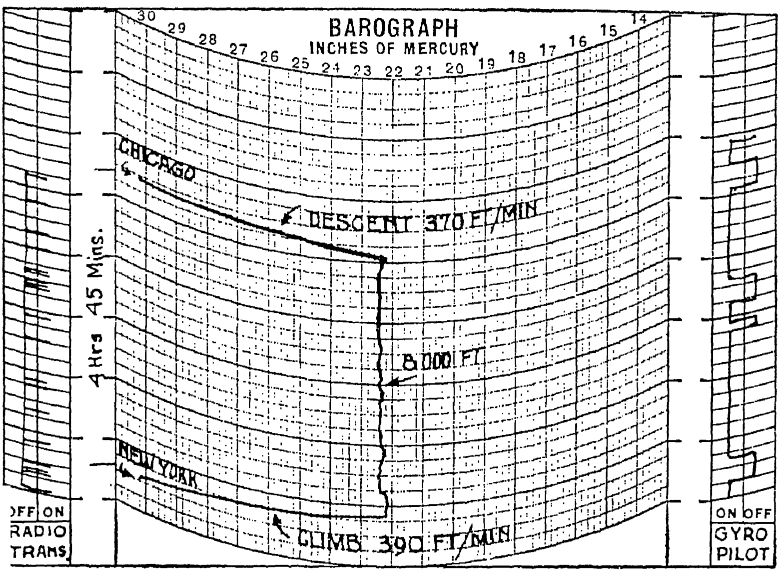


Figure 153. Flight Analyzer
(United Air Lines)

This photograph shows how United Air Lines analyzes flight altitudes to confirm that minimum altitudes are being maintained. This is a photograph of an actual barograph card from a flight analyzer operated on a New York-Chicago flight. Certain explanatory lettering has been added. At left is chart showing number of times radio transmitter was used. At right is chart showing what portions of the trip were flown with the automatic pilot in use. In the center is the barographic altitude record for the New York to Chicago flight.

Altitude-Pressure Variations

It has been previously mentioned that atmospheric pressure decreases with altitude. Table II will elucidate in vernier terms. All altitudes above sea level standard are positive and all altitudes below sea level are negative.

We know that 29:92″ of Hg = sea level pressure. In column 1 is found 29.9″. Following horizontally to column 4 we find .02″ which is added to 29.9″ equaling 29.92″ of Hg or 1 foot altitude. By following this procedure various altitudes in feet may be determined up to 1,824 feet. For greater altitudes Table I should be consulted. Table II is used mostly for the initial setting of the altimeter prior to shop testing.

TABLE II. ALTITUDE-PRESSURE TABLE—FEET-INCHES
BASED ON THE UNITED STATES STANDARD ATMOSPHERE
Altitude in feet, pressure in inches of mercury

P inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
28.0.....	1,824	1,814	1,805	1,795	1,785	1,776	1,766	1,756	1,746	1,737
28.1.....	1,727	1,717	1,707	1,698	1,688	1,678	1,668	1,659	1,649	1,639
28.2.....	1,630	1,620	1,610	1,601	1,591	1,581	1,572	1,562	1,552	1,542
28.3.....	1,533	1,523	1,513	1,504	1,494	1,484	1,475	1,465	1,456	1,446
28.4.....	1,436	1,427	1,417	1,407	1,398	1,388	1,378	1,369	1,359	1,350
28.5.....	1,340	1,330	1,321	1,311	1,302	1,292	1,282	1 273	1,263	1,254
28.6.....	1,244	1,234	1,225	1,215	1,206	1,196	1,186	1,177	1,167	1,158
28.7.....	1,148	1,139	1,129	1,120	1,110	1,100	1,091	1,081	1,072	1,062
28.8.....	1,053	1,043	1,034	1,024	1,015	1,005	995	986	976	967
28.9.....	957	948	938	929	919	910	900	891	881	872
29.0.....	863	853	844	834	825	815	806	796	787	777
29.1.....	768	758	749	739	730	721	711	702	692	683
29.2.....	673	664	655	645	636	626	617	607	598	589
29.3.....	579	570	560	551	542	532	523	514	504	495
29.4.....	485	476	467	457	448	439	429	420	410	401
29.5.....	392	382	373	364	354	345	335	326	317	307
29.6.....	298	289	280	270	261	252	242	233	224	215
29.7.....	205	196	187	177	168	159	149	140	131	122
29.8.....	112	103	94	85	75	66	57	47	38	29
29.9.....	20	10	1	− 8	− 17	− 26	− 36	− 45	− 54	− 63
30.0.....	− 73	− 82	− 91	−100	−110	−119	−128	−137	−146	−156
30.1.....	−165	−174	−183	−192	−202	−211	−220	−229	−238	−248
30.2.....	−257	−266	−275	−284	−293	−303	−312	−321	−330	−339
30.3.....	−348	−358	−367	−376	−385	−394	−403	−412	−421	−431
30.4.....	−440	−449	−458	−467	−476	−485	−494	−504	−513	−522
30.5.....	−531	−540	−549	−558	−567	−576	−585	−594	−604	−613
30.6.....	−622	−631	−640	−649	−658	−667	−676	−685	−694	−703
30.7.....	−712	−721	−730	−740	−749	−758	−767	−776	−785	−794
30.8.....	−803	−812	−821	−830	−839	−848	−857	−866	−875	−884
30.9.....	−893	−902	−911	−920	−929	−938	−947	−956	−965	−974
31.0.....	−983	−992	−1,001	−1,010	−1,019	−1,028	−1,037	−1,046	−1,055	−1,064

Mercurial Barometers

Throughout this chapter, barometers have been mentioned and a full description herewith is given to clearly illustrate the construction and settings. Mercurial barometers because of their accuracy are used in instrument shops as a "master" by which altimeters are calibrated. However, certain corrections must be made which will be explained later.

Fortin Barometers, Weather Bureau Pattern. In order that the height of the mercurial column may represent accurately the true pressure of the air, and in order to detect the comparatively small changes of pressure from day to day, many refinements are necessary in the construction of the instrument and great precision of measurement is required. An excellent form of the mercurial barometer, satisfying the requirements just stated, was devised by Fortin, and is now very widely used the world over.

The barometer consists of a glass tube, about ¼″ inside diameter, closed at the top and inclosed in a thin metal tube, through which large openings are cut on opposite sides, exposing to view the glass tube and mercurial column. The graduated scale is formed at one side of this opening and a short tube or sleeve, also graduated (shown at C, Figures 154 and 155), encircles the barometer tube and slides smoothly within the metal part, motion being given to it by means of the milled head (D), and a small rack and pinion inside.

At (E), Figure 155, is shown what is called the attached thermometer. The bulb of this is entirely concealed within the metal tube, and is between it and the glass barometer tube, so as to show as nearly as possible the mean temperature of both the brass tube and the mercury.

Cistern. The special feature of the barometer is a cistern so constructed that the level of the mercury within may be changed greatly and adjusted to a fixed index point.

The topmost portion of the cistern consists of a small boxwood piece (G), Figure 156. The glass tube (t) passes through

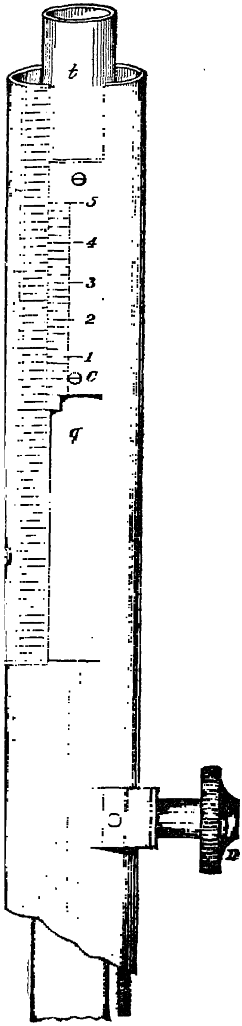


Figure 154

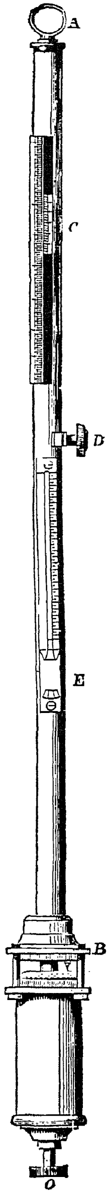


Figure 155

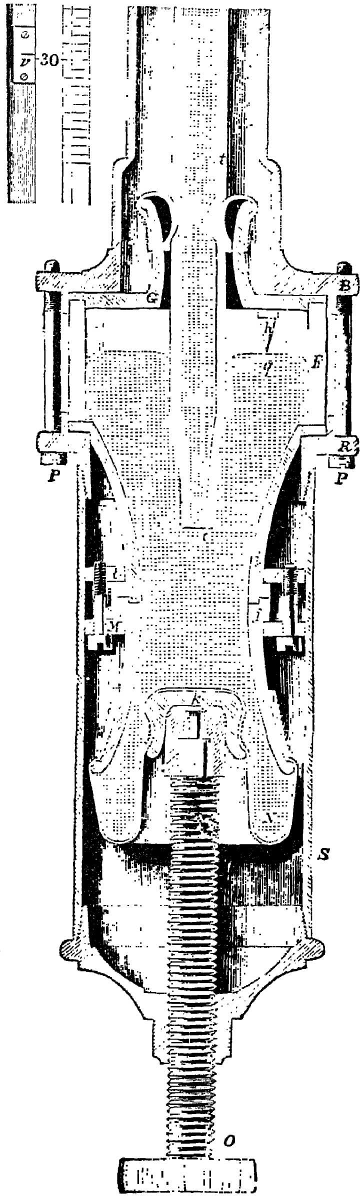


Figure 156

Mercurial Barometer, with Fortin Cistern *(U. S. Weather Bureau)*

the central portion of this, to which it is secured by a piece of soft kid leather folded in a peculiar manner and securely wrapped to both the glass tube and the boxwood cap (G). The flexible joint thus formed will not allow the mercury to escape, but permits the passage of air to and from the cistern.

The remaining portions of the cistern are the short glass cylinder (F), Figure 156, the two curved boxwood pieces (i) and (j), and the kid leather bag (N), with adjusting screw (O), clamps, etc.

It is plainly seen that on turning the screw (O), the leather bag may be folded up into or withdrawn from the curved boxwood chamber (j), in a manner to cause any desired change in the level of the mercurial surface.

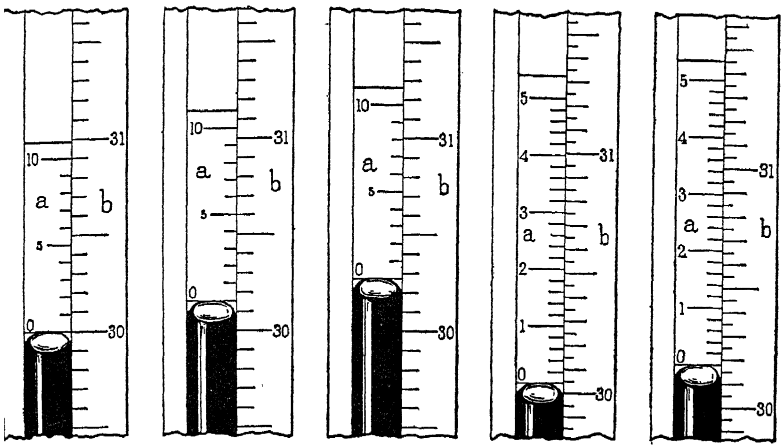
Ivory Point. At (h), Figure 156, is shown what is technically called the "ivory point," which projects downward from the top of the cistern and forms a fixed and definite point, to which the level of the mercury in the cistern can be adjusted in taking readings. The ivory point is, therefore, the zero end of the scale, from which all the measurements of the height of the column are made.

Scale of Barometer. The scale of the barometer is seen on the left of the opening, at the top.

VERNIER. A vernier is a device by which one is able to ascertain accurately much smaller fractional subdivisions of a graduated scale than could otherwise be observed by the eye without the aid of a microscope. For example, with a scale having only 20 subdivisions to the inch a vernier enables one to ascertain accurately the one-thousandth part of an inch. This portion of the barometer is the little graduated scale (C), Figures 154 and 155. A vernier consists, essentially, of a small graduated scale, the spaces upon which are just a certain amount smaller or larger than those on the main scale. When two such scales are placed together some particular line of one will always be coincident, or very nearly so, with a line of the other and from this circumstance the position of the zero line of the vernier in reference to the scale can be very accurately

determined as will be readily understood from a study of the following figures and explanation:

Figure 157 exhibits the manner of graduating a vernier so as to subdivide the spaces upon the scale into tenths. In the figure, (b) is the scale and (a) is the vernier. The lower edge of the vernier, which is also in this case the zero line, is exactly opposite or coincident with 30 on the scale. The tenth line on the vernier is coincident with the ninth line above 30; that is a space of 9 divisions on the scale is divided into 10 spaces on the vernier, so that each space on the latter is one-tenth part shorter than a space on the scale.



30.00 Figure 157 | 30.15 Figure 158 | 30.277 Figure 159 | 30.034 Figure 160 | 30.177 Figure 161

Verniers
(U. S. Weather Bureau)

In the present case the spaces on the scale represent inches and tenths; hence the difference between the length of a space on the vernier and one on the scale is 1/10 of 1/10 = 1/100 of an inch. This principle of matching two scales having spaces of slightly different magnitude is always followed in the construction of verniers, though, of course, the number of spaces embraced by the vernier is varied to suit the circumstances and the degree of minuteness desired. Moreover, in some instances,

the vernier embraces one more space on the scale, instead of one less, than the number of its own subdivisions; that is, 10 on the vernier may be made to correspond to 11 spaces on the scale.

If, as we have seen, the spaces on the vernier are one-tenth smaller than on the scale, then, in the adjustment shown in Figure 157, the first line above the zero on the vernier is one-tenth part of the space, the next line two-tenths, the next three-tenths, etc., distant from the line next above on the scale. When, therefore, we find the vernier in such a position as shown in Figure 158, where the fifth line on the vernier is coincident with a scale line, it is very clear that the zero line of the vernier must be just five-tenths above the scale line next below. Now, since we imagine these scales to represent inches and tenths, then Figure 158 will read 30.15″.

Estimation of Fractions on a Vernier. In many cases it will happen that no single line on the vernier will be exactly coincident with a scale line, but that one line will be a little above while the next line on the vernier will be a little below the corresponding scale lines.

In the case shown in Figure 159, the seventh and the eighth lines on the vernier are each nearly in coincidence, but neither one is exactly so. This indicates that the reading is somewhere between 30.27 and 30.28. Moreover, we can clearly see that the eighth line is nearer coincidence than the seventh. We, therefore, estimate that the true reading is about 30.277. We might, probably, with as great accuracy have selected 30.278.

In Figures 160 and 161 are shown verniers applied to a barometer scale having 20 parts to the inch. In this case 24 parts on the scale are divided into 25 parts on the vernier. By the principle already explained, the value of the subdivisions effected by such a vernier, or, as it is most frequently expressed, the least count of the vernier, will be $1/25$ of $1/20 = 1/500$ of an inch. In reading the vernier, therefore, each line will represent 0.002″, so that the fifth, tenth, fifteenth, twentieth and twenty-fifth lines will represent one, two, three, four, and five hundredths of an inch, respectively, and are so numbered.

Barometer Corrections

The following corrections should be subtracted from the observed readings of a mercurial barometer having a brass scale, in order to eliminate from the barometer reading the effect of temperature in expanding the mercury and the scale.

TABLE III

Temperature °F	Mercury with Brass
70	0.109
75	.122
80	.135
85	.148
90	.161
95	.174
100	.187

The following example will elucidate the use of Table III.

The attached thermometer of a barometer reads..............	70° F.
The barometer reads..	29.000″ Hg
The reading corrected for temperature is, therefore............	29.000″ Hg
	− .109″ Hg
	28.891″ Hg

Test Apparatus

Figure 163 is a pressure chamber used for checking and calibrating altimeters and rate of climb indicators. It is adaptable for checking these instruments with the barometer, Type E-801, Figure 162, which has scales graduated in feet or meters of altitude as well as in millimeters of mercury.

Four instruments may be checked at one time; these are mounted on a rack which slides into the chamber through a hinged door. The door incorporates three quick acting and easily operated clamps, tightly closing the chamber and providing a seal easily withstanding the vacuum required in tests.

For supplying the necessary suction, a motor-driven vacuum pump for operation on either AC or DC is recommended. This source of suction is connected to a vacuum manifold installed in the stand below the chamber. The manifold is provided with two hand-operated needle valves, the one controlling

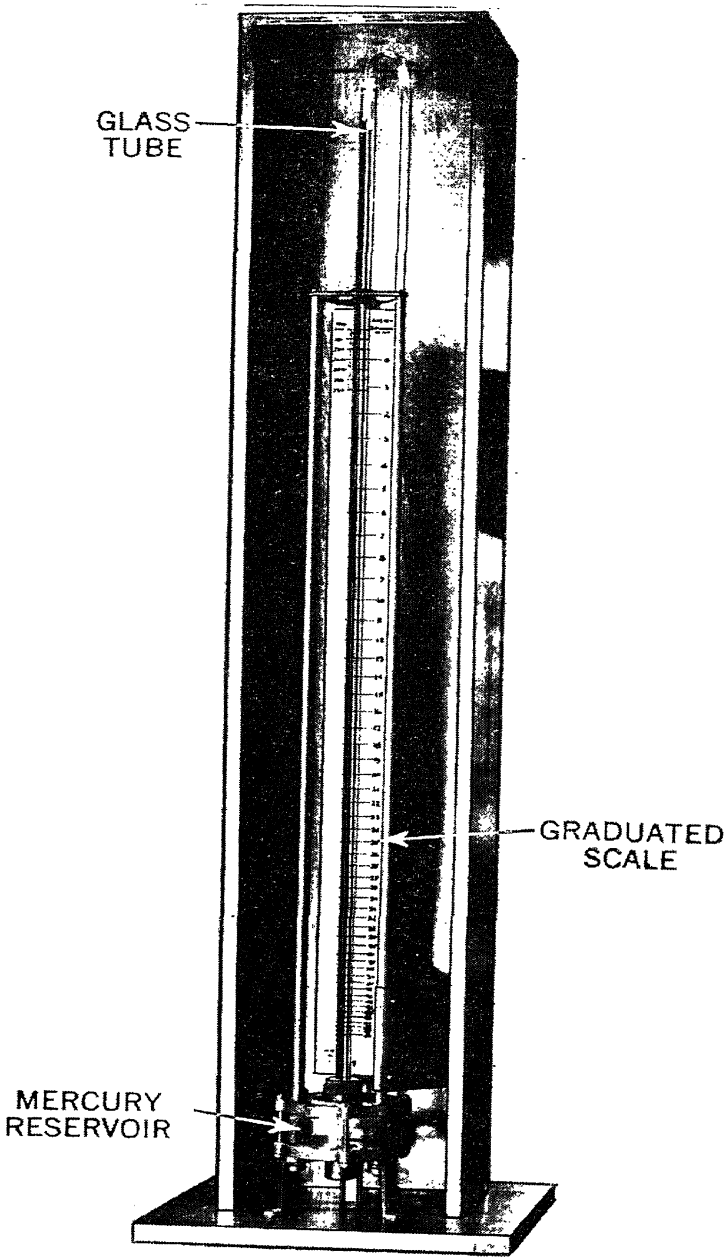


Figure 162. Pioneer Mercurial Barometer Type E-801
(Pioneer Instrument Division of Bendix Aviation Corp.)

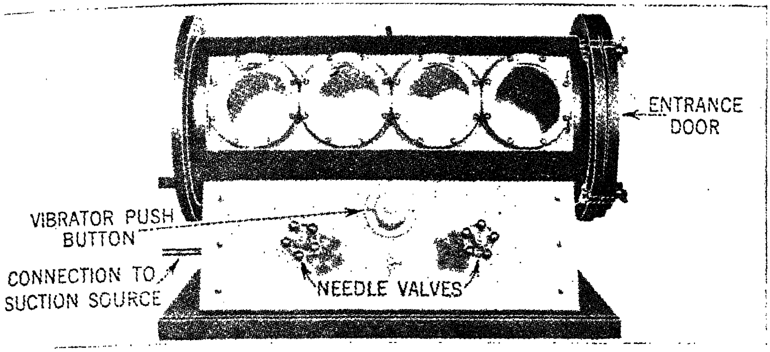


Figure 163. Pioneer Altimeter Test Chamber Type E-21
(Pioneer Instrument Division of Bendix Aviation Corp.)

the suction and the other in air bleed from the outside pressure. The barometer is connected to the air chamber through a rubber tubing.

A vibrator mounted in the chamber is controlled by a push button and switch on the front and operates on low voltage through a transformer installed inside the stand. The vibrator is used to uniformly take out possible friction errors.

Directions for Shop Testing

Rotate the pointers of the altimeter under test to indicate the plus or minus number of feet off zero corresponding to the barometer, after temperature correction is made. Place the instrument on the rack provided in the chamber and tightly close the door. Evacuate until the barometer reads zero. The altimeter should also read zero; if not, check again the preliminary setting of the hand.

The following checks should then be made and apply only to Pioneer Sensitive Type 1501-1A. For all other types and makes the manufacturer's test manuals should be consulted.

Scale Error Test. With the counter set to the existing barometric pressure, the instrument shall be tested for scale error by subjecting it successively to the pressures listed below. The pressure shall be reduced at a rate not to exceed 3,000 ft./min.

The errors at the test points shall not exceed the tolerances specified.

Altitude Feet	Pressure In. of Mercury	Tolerance Feet
0	29.92	30
1,000	28.85	..
2,000	27.82	40
4,000	25.84	60
5,000	24.89	..
6,000	23.98	80
8,000	22.22	100
10,000	20.57	120
12,000	19.02	140
14,000	17.57	160
16,000	16.21	180
18,000	14.94	200
20,000	13.74	220
22,000	12.63	260
24,000	11.59	300
28,000	9.72	370
32,000	8.10	440
35,000	7.04	500

Hysteresis and After Effect Test. Subject the instrument to a pressure corresponding to maximum indication for a period not less than 5 and not more than 8 minutes. Increase the pressure at a rate corresponding to 3,000 ft./min. until a pressure corresponding to 16,000 ft. is reached. Hold this pressure for at least 10 minutes and take a reading. Increase the pressure until atmospheric pressure is reached. The reading of the instrument at 16,000 feet shall not differ from the corresponding reading of the scale error test of section by more than 70 feet. Three minutes after the instrument has reached atmospheric pressure, the hands shall have returned to their original position, corrected for any change in barometric pressure, within 50 feet.

Position Error Test. With the instrument held so that the dial is in a normal upright position and the hands on zero rotating the instrument 45° to the right or left shall cause a change in indication no greater than 15 feet.

Friction Test. The instrument shall be tested for friction at the points listed below. The pressure shall be brought up to the desired indication and then held constant while two readings are taken, the first before the instrument is tapped, and the second after. The difference between any set of two readings shall not exceed the tolerances listed below:

Altitude Feet	Tolerance Feet
1,000	..
2,000	50
16,000	85
35,000	100

Barometric Counter Test. Corrected for barometric pressure variations the barometric counter reading shall be compared with the reading of the hands against the dial. This test shall be made by turning the knob while the instrument is lightly vibrated or tapped. The indication of the hands shall not vary from the reading of the counter by more than the tolerance given below:

Counter Setting	Tolerance—Feet
28 to 30.49″ Hg	15
30.50 to 30.99″ Hg	25

Case Leak Test. The connection on the back of the case shall be suitably connected to a source of suction equivalent to 1,000 feet indicated altitude. With the source disconnected during a period of one minute, the fast hand shall not move more than 50 feet. Turning of the barometric counter setting knob shall show no effect.

Insulation Breakdown Test. On lighted instruments with the lamp removed, 550 volts at a commercial frequency applied for one minute shall cause no breakdown in insulation.

Installation

The altimeter should be mounted next to the rate of climb-vertical speed indicator. By means of a "T" fitting it should be connected into the static line of the pitot-static tube to the air-speed indicator using 3/16″ O.D. tubing.

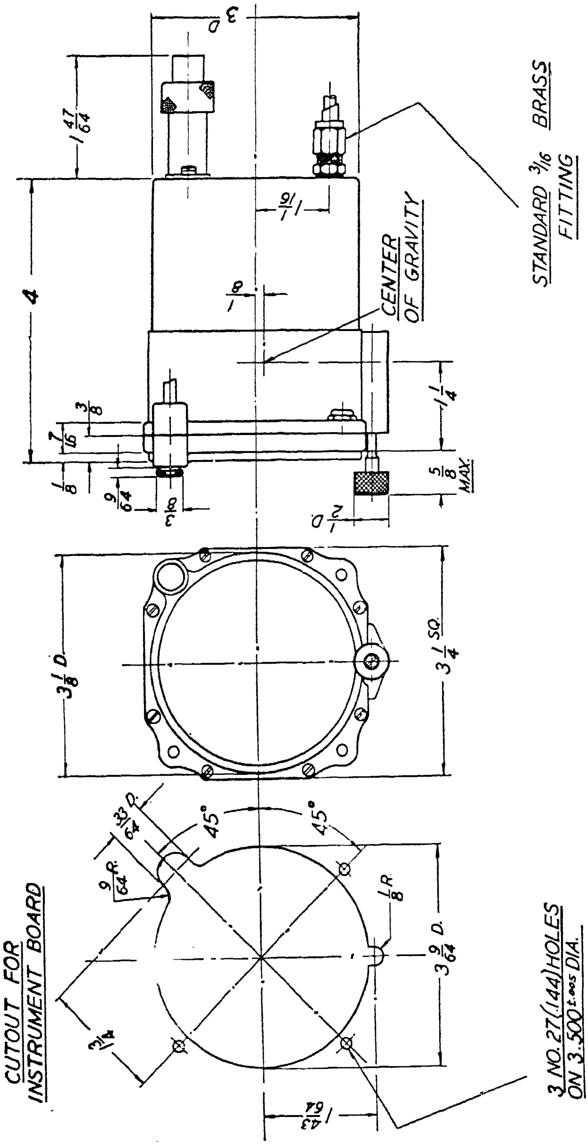


Figure 164. Installation Dimensions Pioneer Type 1501-1A
(Pioneer Instrument Division of Bendix Aviation Corp.)

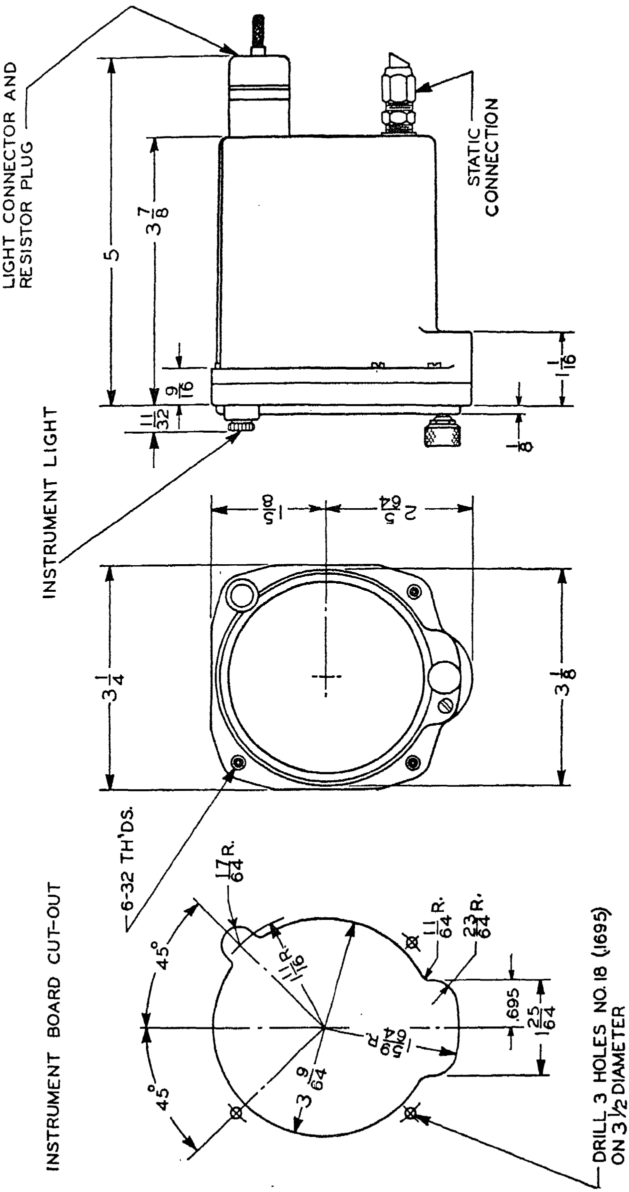


Figure 165. Installation Dimensions Kollsman Type 497K-01
(Kollsman Instrument Division of Square D Co.)

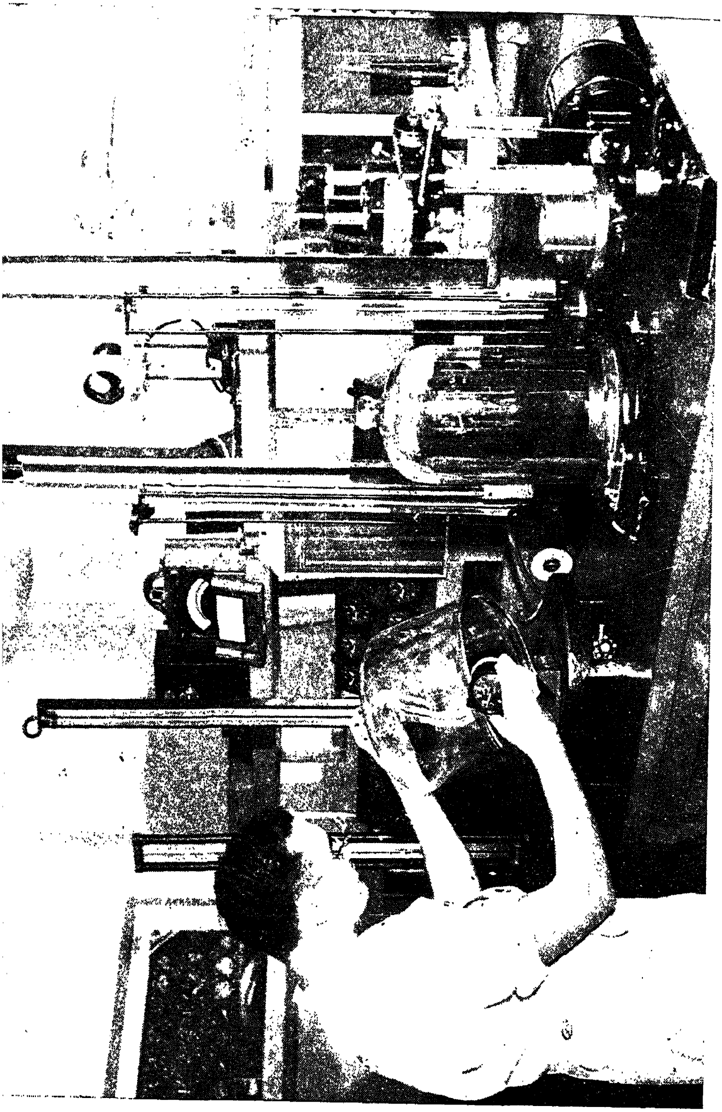


Figure 166. A T.W.A. Instrument Technician Prepares to Check an Altimeter under the Bell Jar After Final Assembly

(Transcontinental and Western Air, Inc.)

Maintenance

In the event of unsatisfactory operation of the sensitive altimeter the following points should be checked before the instrument is removed from the airplane:

(a) WATER IN STATIC LINE. Disconnect all instruments from the static line and blow it out with compressed air at moderate pressure.

(b) LEAK IN LINE ON CASE. Apply suction to the static tube openings until the instrument reads about 1,000 feet, and pinch off. If the pointer returns at a rate faster than 50 feet per minute check all connections for leaks.

Caution: If vertical speed and air-speed indicators are connected to the static line for this test, apply suction very gently to prevent injury to the diaphragms of these instruments.

After the connections are made tight, if the pointer still drops back faster than the rate given above, the leak is probably around the cover glasses of the instruments connected to the static line.

(c) ZERO SHIFT. The instrument should be inspected approximately every three months, when in regular service, for possible changes in indication due to the release of internal stresses in the diaphragm. This may readily be determined by setting the pointers at zero and comparing the reading of the barometric scale with the reading of the field barometer in inches of mercury.

CHAPTER 21

WESTERN ELECTRIC RADIO ALTIMETER

One of the most important navigational factors in aviation is that of altitude. Until now, altitude of necessity has been considered with reference to "sea level." With the development of the Western Electric Radio Altimeter, altitude becomes "distance above ground," or "clearance between plane and terrain," a measurement of incalculable value to flying personnel. This instrument was first commercially available in 1938.

The radio altimeter gives continuous and instantaneous readings of the distance between plane and terrain throughout an altitude range of from 50 to 5,000 feet. The indication of altitude is independent of changes in air pressure, temperature inversions, humidity, cloud layers, and other variable factors of weather. It is not affected by static and requires no adjustment by the pilot.

Operation and Theory

The fundamental parts of the altimeter in relation to their application are shown in Figure 168. An ultra-high frequency oscillator is provided, whose frequency is varied up and down by a modulator which consists of a small rotating variable condenser driven by a motor. The oscillator is connected through a coaxial transmission line to a transmitting antenna which is located on one of the lower surfaces of the airplane. The signal is radiated downward by this antenna. A radio receiver is connected through a similar coaxial line to a second antenna similarly located but arranged in such a way that a minimum of direct signal is received from the transmitting antenna and as much radio echo as possible from the ground. The direct and reflected signals are applied to a detector circuit

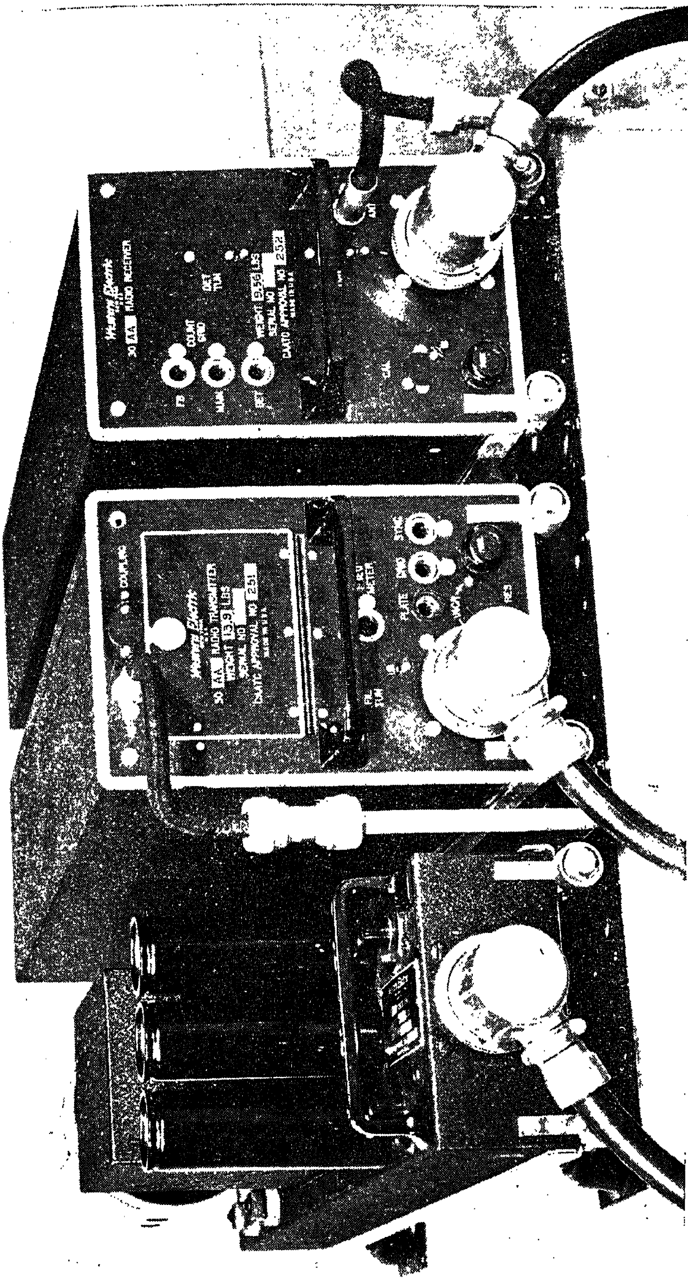


Figure 167. The Principal Components of Western Electric Radio Altimeter Equipment—Power Unit, Transmitter and Receiver
(Western Electric)

in the receiver. The output of this detector is a signal of a frequency equal to the instantaneous difference existing between the direct and the reflected signals and is proportional to the height of the plane above the terrain. This signal is amplified by the receiver and applied to a frequency meter or counter circuit which is so designed that a current proportional to the frequency and, hence, to the height flows through a meter calibrated in feet and located on the airplane's instrument panel.

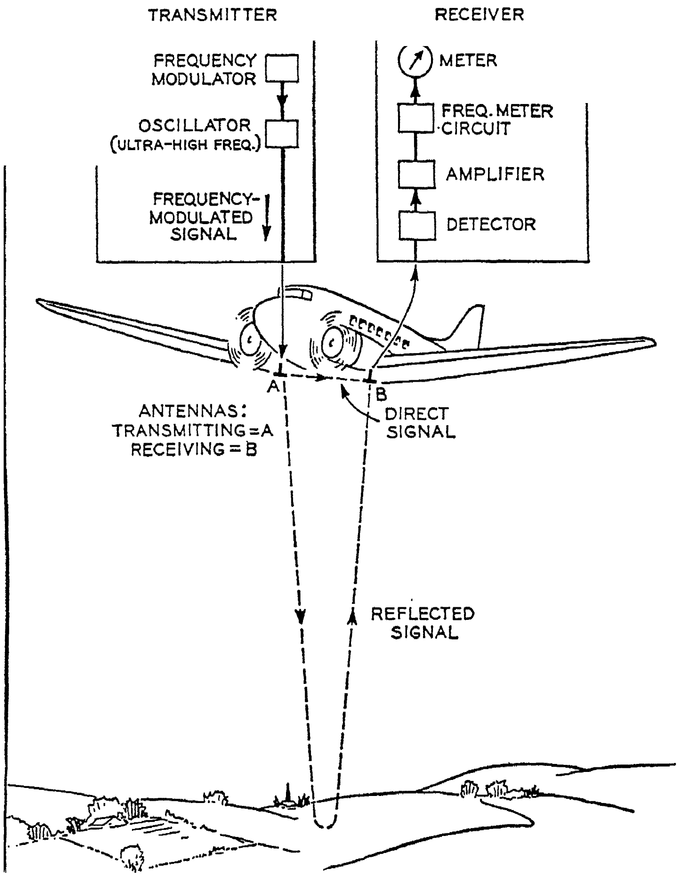


Figure 168. Overall System

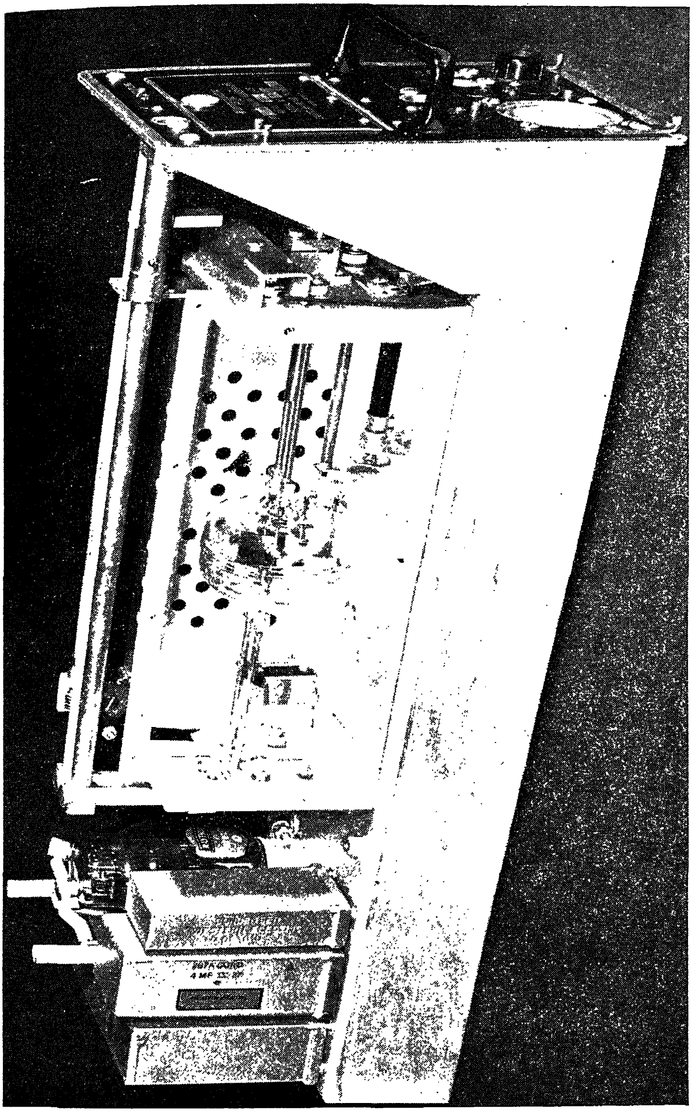


Figure 169. 30AA Radio Transmitter Chassis—RF Cover and Tube Supports Removed
(Western Electric)

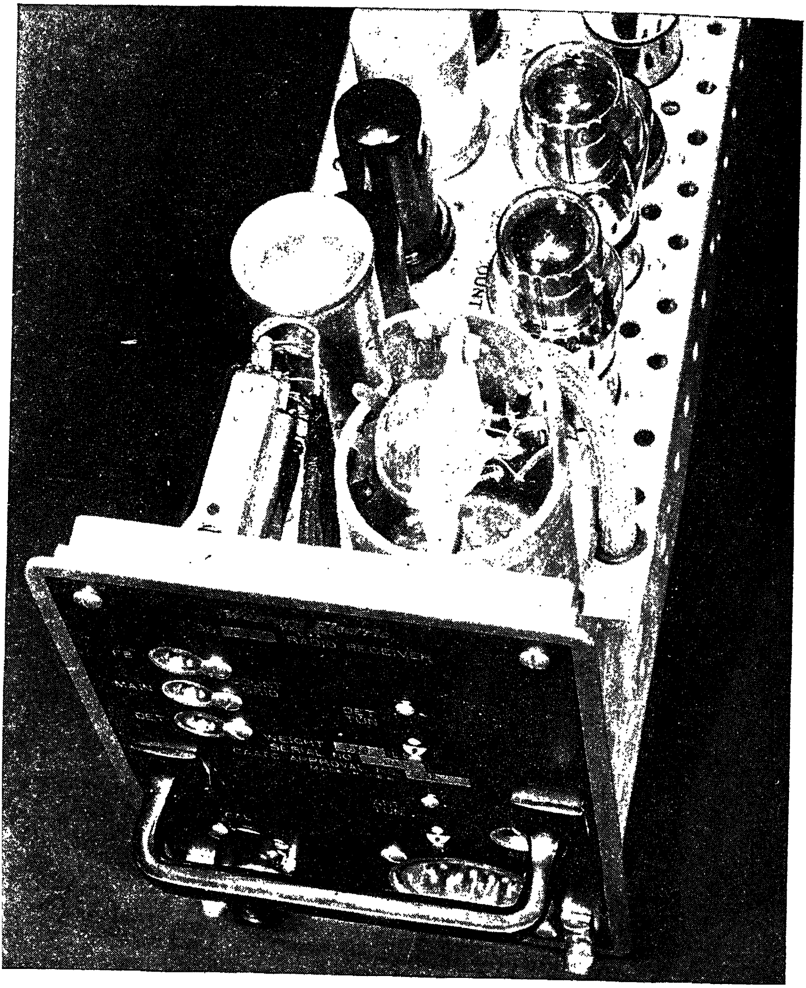


Figure 170. 30AA Radio Receiver—Closeup of Detector with Cover Removed
(Western Electric)

Use in Flight

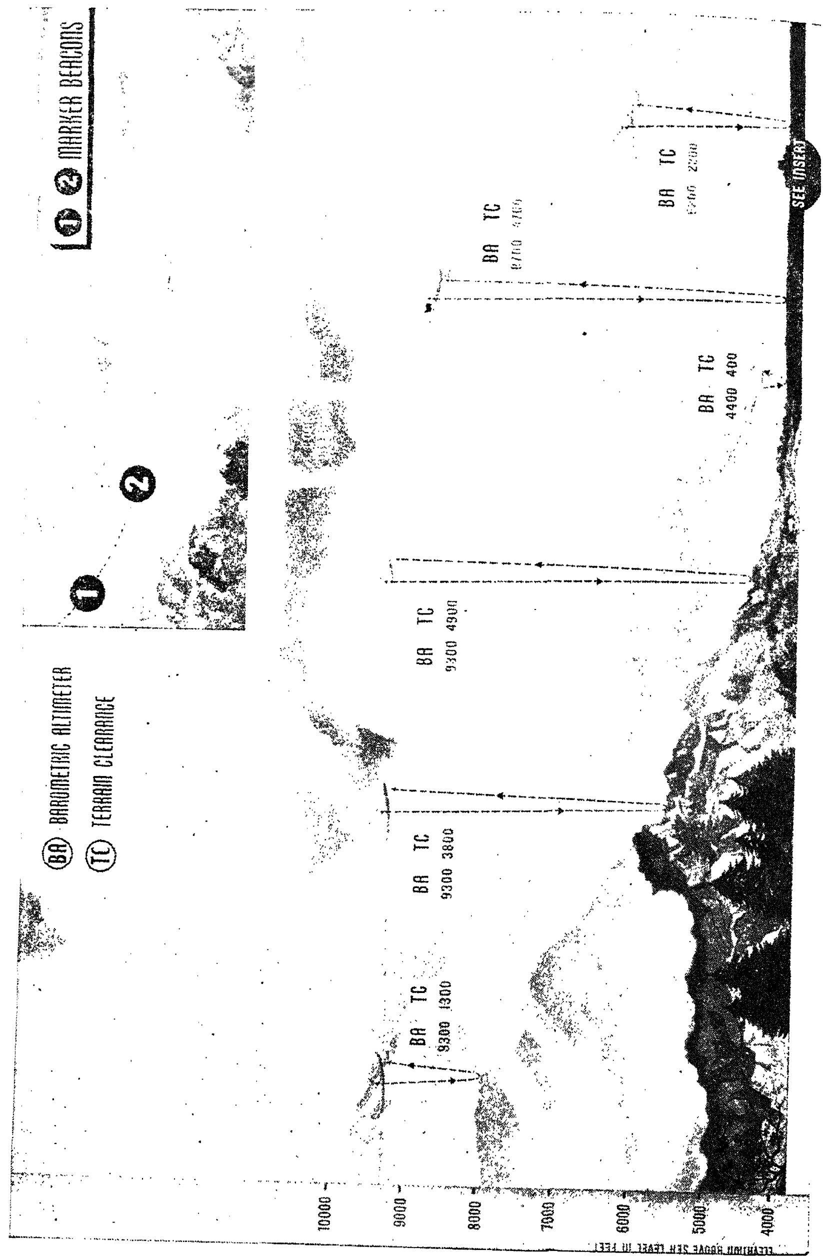
At the take-off of a flight, when the airplane is only about 50 feet above ground level of the airport, a continuous indication of altitude is shown by the terrain clearance meter. As the altitude increases, the position of the instrument's needle changes to indicate greater distance above the ground until the altitude exceeds 5,000 feet. Then the needle of the instrument remains off-scale until the altitude exceeds 12,000 feet. In the range of 12,000 to 15,000 feet and above, the needle of the instrument may drop back momentarily on the scale. The reason for this is that the intensity of the radio signal is low at the higher altitudes and irregular variations occur with the result that insufficient signal is received to operate the equipment satisfactorily.

In cross-country flight the indication of altitude above the ground will show variations according to the contour of the terrain below the airplane. This information together with a map showing the contour of the airway sector and a reference altitude of constant level obtained from a sensitive, aneroid-type altimeter may be used to locate the position of the airplane as a navigation procedure when flying above clouds or by instruments. By this method, prominent ridges and peaks of mountain ranges may be located, using the indication of the sensitive barometric altimeter as a level flight reference.

In Approaching an Airport

In making an instrument approach to an airport or breaking through a cloud layer the radio altimeter will indicate the height of the airplane above the ground directly below it. As the airplane descends to a runway, the indicated altitude is reduced correspondingly until zero is reached when the landing wheels are very close to the ground. No correction to the reading of the terrain clearance indicator is required despite the elevation of the airport.

The radio altimeter will not indicate the height of the airplane above objects having a relatively small area. For example, if the airplane passes over a building, only a slight



1 2 MARKER BEACONS
BA BAROMETRIC ALTIMETER
TC TERRAIN CLEARANCE
1
2
BA TC
9300 1300
BA TC
9300 3800
BA TC
9300 4900
BA TC
4400 400
BA TC
BA TC
SEE INSERT
10000
9000
8000
7000
6000
5000
4000
ELEVATION ABOVE SEA LEVEL IN FEET

momentary dip in the altitude indication is observed on the terrain clearance meter.

This is due to the fact that the radio wave sent down from the airplane is reflected back to it from quite a large area and the received signal is the resultant integration of waves reflected back from many elementary areas. When the plane passes over buildings, the waves reflected back by the roof areas (of the buildings) are relatively a small portion of the total reflected back by a much larger area.

Radio waves or signals are reflected best from smooth salt water, less perfectly from rough water and ground with wooded terrain. Very rough ground will produce sufficient irregularity in the reflected wave to cause the needle of the terrain clearance meter to swing back and forth over a small arc on the scale of the meter.

Terrain Clearance Meter

The terrain clearance meter should be removed from the airplane occasionally and checked against an accurate milliammeter. Connect the two meters in series with a suitable battery and

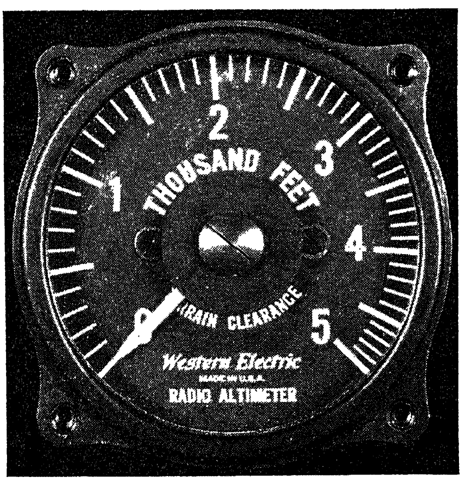
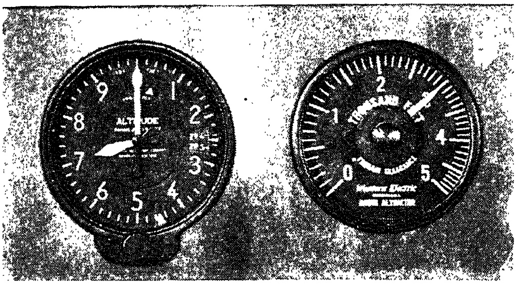


Figure 172. Terrain Clearance Meter
(Western Electric)



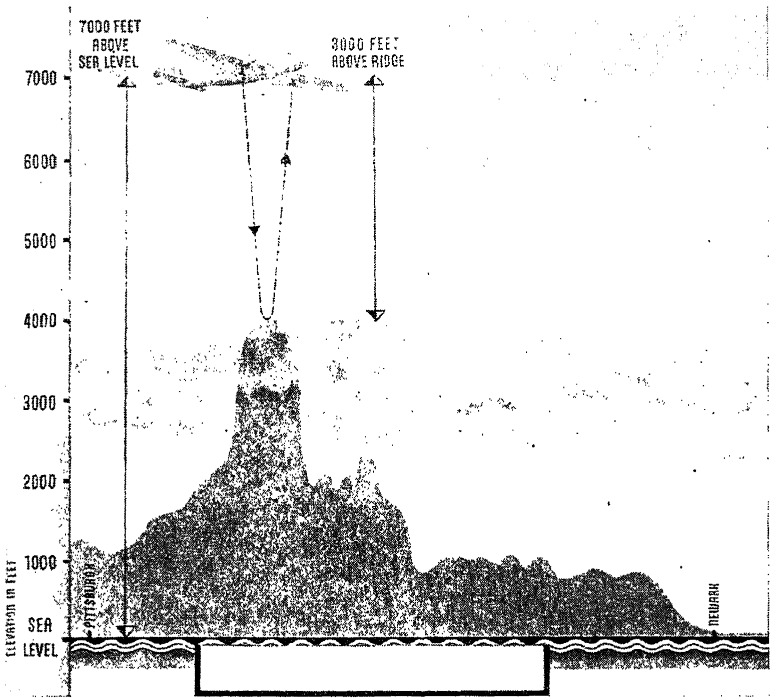


Figure 173. Advantage of Terrain Clearance Indicator over Barometric Altimeter
(Western Electric)

Graphic demonstration of the advantages of the Western Electric terrain clearance indicator. The dial faces above show readings which a pilot might take over the highest point between Pittsburgh and Newark. The conventional barometric altimeter (left) shows the plane's height above sea level to be 7,000 feet, while the terrain clearance indicator dial shows the plane's actual height above terrain to be only 3,000 feet. In cross-country flight the indication of altitude above ground will show variations according to the contour of the terrain below the airplane. Thus, the pilot familiar with the topography along his route is provided with a supplementary navigational aid.

rheostat. The calibration should be as indicated in the following table. The resistance of the meter is approximately 560 ohms.

Feet	m.a. d-c
0	0
500	0.260
1,000	0.500
1,500	0.725
2,000	0.940
2,500	1.14
3,000	1.33
3,500	1.51
4,000	1.68
4,500	1.85
5,000	2.00

Location of Troubles

Any trouble which may develop in the altimeter equipment generally will be indicated by failure to obtain correct readings or adjustments. In order to assist in the location of the cause of any abnormal effects which may be observed and reported by the pilot, a list is given below of some of these abnormal effects and some of the more probable causes thereof.

No Meter Reading. Failure of the "Terrain Clearance" meter to read at any altitude could result from any one of the following causes:

(a) No plate voltage.
(b) Frequency modulating motor not running.
(c) No transmitter output.
(d) Burned-out tube.
(e) Open meter circuit.
(f) Short circuited meter damping condenser.
(g) Short or open-circuited antenna or transmission line.

Low Meter Reading. Consistently low readings will be obtained in any of the following cases:

(a) Improper calibration.
(b) Frequency modulating motor not in synchronism with sixty-cycle oscillator.

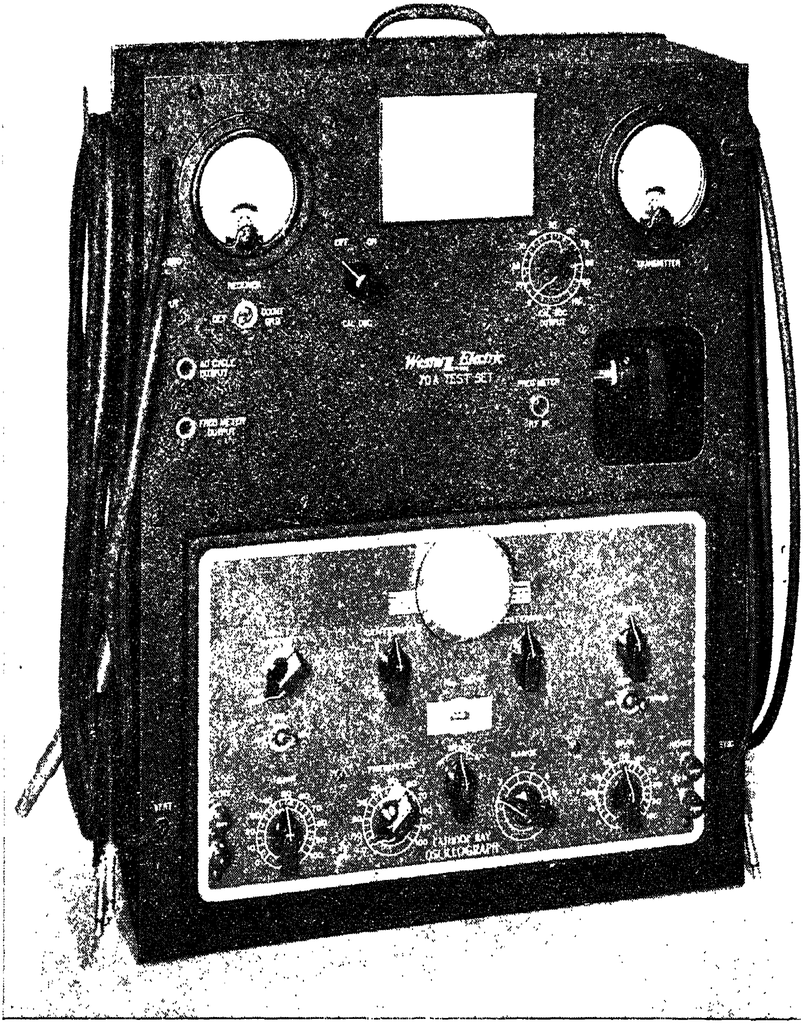


Figure 174. 70AA Test Set
(Western Electric)

(c) Sixty-cycle oscillator frequency low.
(d) Ground on one side of meter circuit.
(e) Leaky meter damping condenser.

High Meter Reading. This generally is the result of improper calibration. However, high readings may be obtained in the range from 1,000 to 3,000 feet when flying over rough terrain if the receiver gain is excessive. A reading of 100 to 200 feet high in this altitude range when flying over trees or buildings is normal.

Low Unsteady Reading. This effect generally results from lack of sufficient signal strength. Some of the probable causes are:

(a) Low transmitter output.
(b) Radio receiver detuned.
(c) Low receiver gain.
(d) Low plate voltage.

High Unsteady Reading. If the readings obtained below 1,000 feet are high and unsteady the trouble probably lies in the feedback control circuit in the radio receiver.

Failure at High Altitude. If the meter fails to read after banking steeply at high altitude the interlock circuit should be tested. Low voltage output from the feedback counter might also cause failure at high altitude.

Installation

The component parts of the 1B radio altimeter equipment are shown in the outline dimensional drawing of Figure 180 and Figure 179. The photograph shows only short sections of coaxial transmission line to the two antennas. Actually, two 20-foot lengths are provided with the equipment, and the location of the antennas with respect to the radio transmitter and radio receiver should be such that this length is not exceeded.

Antennas. The two 52A antennas should be located about 12 to 18 feet apart on the lower metallic surface of the airplane

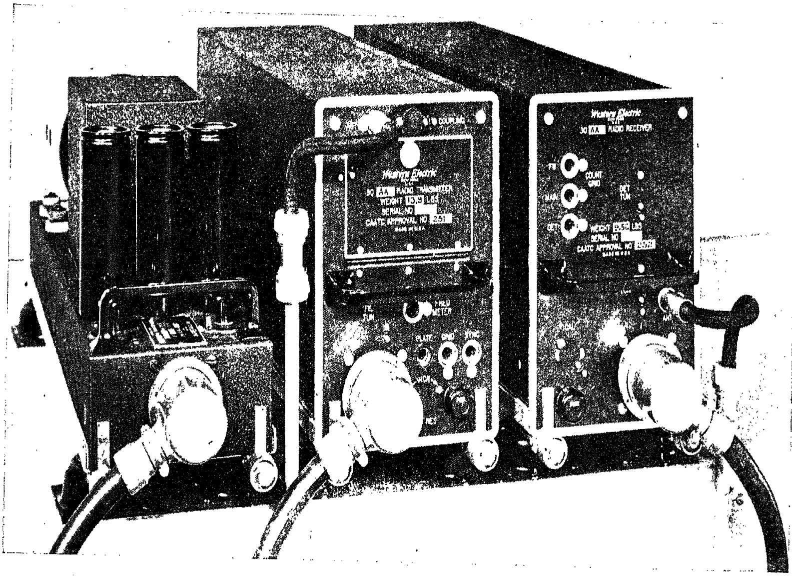


Figure 175. Apparatus Installation Photograph
(Western Electric)

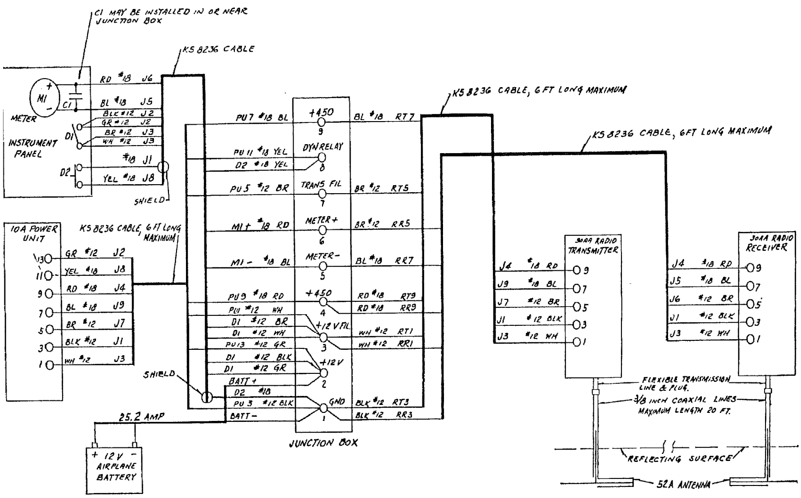


Figure 176. Diagrams of Connections

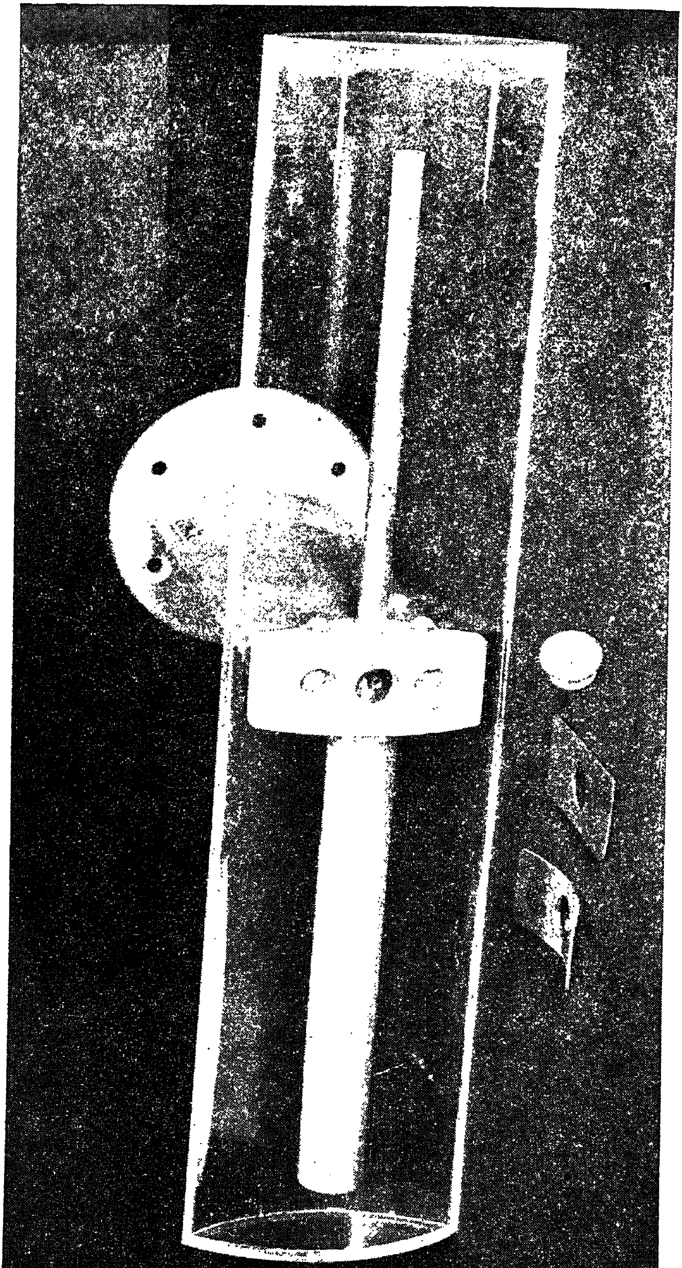


Figure 177. 52A Antenna—Bottom View—Cover Plate Off
(Western Electric)

and on a line at right angles to the direction of motion of the airplane. On large planes, the antennas may be mounted in the space between the two engine nacelles and to the rear of the gas tanks. It is desirable to have the antennas pointed end on, and as nearly as possible in the same straight line, in order to minimize the direct signal between antennas.

On high-wing monoplanes both antennas may be mounted in one wing or one may be mounted in a wing and the other under the fuselage. It does not appear to be desirable to mount one antenna in each wing on this type of plane on account of the shielding effect of the fuselage.

On fabric-covered airplanes metal reflectors at least 3 feet square should be installed at the base of the antennas.

The metallic surface upon which the transmitting antenna is mounted preferably should be more than 4 feet above the ground. If this distance is less than 4 feet the proximity of the ground may change the frequency sweep of the transmitter with the result that a calibration of the equipment made with the airplane on the ground will be inaccurate in flight. In cases where it is not possible to obtain this height the equipment must be calibrated in flight and a correction factor determined which may be applied to future ground calibrations.

The antennas are of special design to obtain broad-band characteristics, and considerable care should be exercised in their installation. The coaxial transmission line is also of special design with close fitting beads to minimize variation in the line characteristics due to vibration of the inner conductor and beads. This line should be installed in one piece and the radius at bends should not be less than 8″.

Details of the antenna installation are shown on Figure 178. The antenna is fastened to the wing surface by means of six flat-head screws, the nuts for which should preferably be elastic stop nuts riveted or spun into the mounting surface so that the antenna may be installed or removed without the use of a wrench to hold the nuts.

Before screwing the antenna in place the transmission line should be installed in approximately the desired run from the antenna to its associated apparatus unit and the antenna end

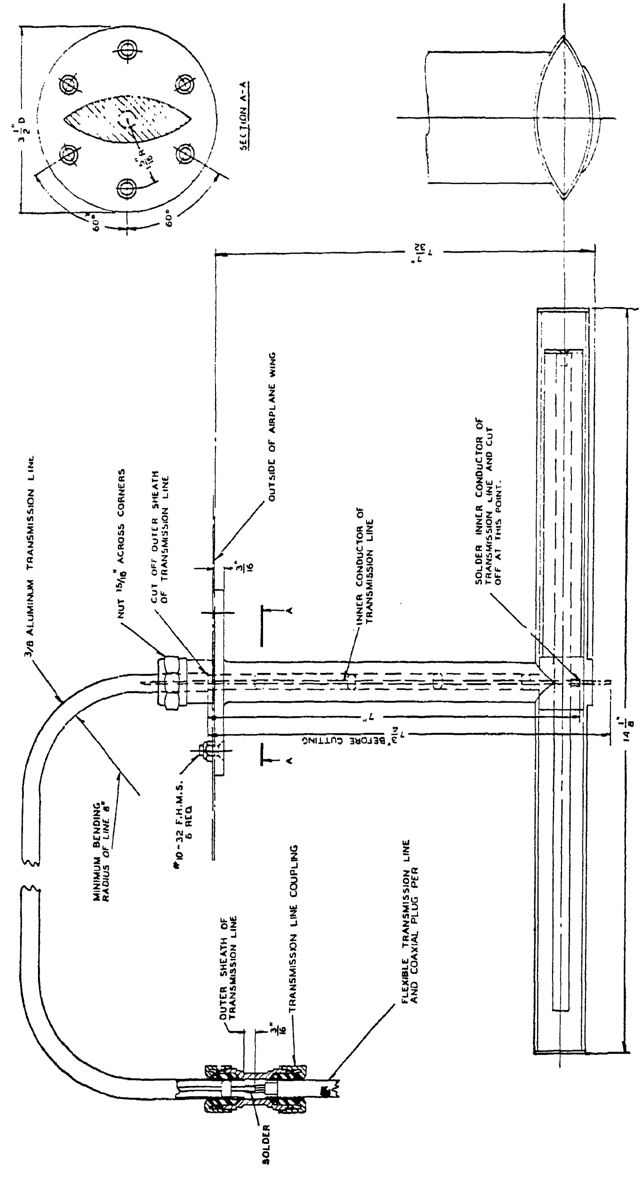


Figure 178. 52A Antenna—Installation Diagram

of the line should extend out of the mounting hole for approximately 1 foot. The outer conductor should then be cut off at a point such that about 7¾″ of inner conductor is exposed. The location of the beads on this exposed section should be approximately as shown in Figure 178. The end of the inner conductor should then be tinned to facilitate soldering into the antenna rod. Remove any excess solder from the conductor by wiping and remove any burrs from the end of the conductor, so that it will readily slip into the hole provided in the antenna rod. Remove the cover plate from the center of the antenna (see Figure 177), and loosen the nut at the upper end of the antenna support. Slide the antenna up over the inner conductor of the transmission line, making sure that the conductor comes through the hole in the antenna rod and that the outer conductor seats in the upper end of the antenna support. The transmission-line clamping nut at the top of the antenna support should now be tightened with sufficient force to expand the rubber insert and provide good contact between the nut and the outer conductor. The antenna may then be screwed in place in the airplane wing, after which the inner conductor of the transmission line should be soldered into the sleeve in the antenna rod and the conductor should be cut off even with the end of the sleeve. The cover plate and gasket should then be screwed in place over the center of the antenna.

The transmission line should be supported at intervals inside of the wing or fuselage and may be either insulated from the supports or electrically connected thereto. If the latter method is used, the usual bonding precautions should be observed.

At the apparatus end of the transmission line the flexible connectors and coaxial plugs should be attached. The location of the lines and connectors with respect to the units is shown in the photograph of Figure 175 and the details of attachment are shown on Figure 178. To attach the flexible connector, loosen the two nuts on the Raybould coupling and slide the entire coupling down over the transmission line. Then solder the inner conductor of the line into the sleeve provided on the flexible connector, being careful to prevent any solder or resin from flowing down inside the line. The coupling should then

be slipped up into place and the nuts tightened sufficiently to compress the rubber inserts in the coupling to provide good electrical contact to the outer conductors of the line and flexible connector.

Radio and Power Units. The 30AA radio transmitter, 30AA radio receiver and 10A power unit may be mounted together as shown in Figure 175. Power cables and the antenna transmission lines should have sufficient slack to permit complete freedom of motion of the units on their respective shock mountings. If the altimeter equipment is to be mounted in a compartment with other radio equipment, it is desirable to locate the receiver a short distance from any power supply or high-level audio-frequency units to prevent inductive pick-up from these units. For the same reason the 10A power unit is not mounted immediately beside the 30AA radio receiver.

The diagram of connections of the 1B radio altimeter equipment is shown on Figure 176. The cables from the power unit, radio transmitter, and radio receiver terminate in a junction box and a fourth cable extends from the junction box up to the airplane instrument panel. The three power cables provided with the equipment have a maximum length of 6 feet. Where this length is not sufficient to reach to the airplane junction box, an auxiliary junction box should be installed and No. 6 leads should be connected between the battery terminals in this junction box and the corresponding terminals in the airplane junction box. It is suggested that the power cables be given an identifying mark to prevent connection to the wrong unit.

The indicating meter, two power switches, and the meter damping condenser are shown mounted on the instrument panel. If desired, however, the damping condenser may be mounted in or near the junction box and connected across the meter terminals at this point. The damping condenser is a 750 microfarad electrolytic condenser and the correct polarity of connections must be observed. The can of the condenser is the negative terminal and must be insulated from ground.

Note: If the instrument panel is not shock-mounted, adequate shock-mounting should be provided for the indicating meter.

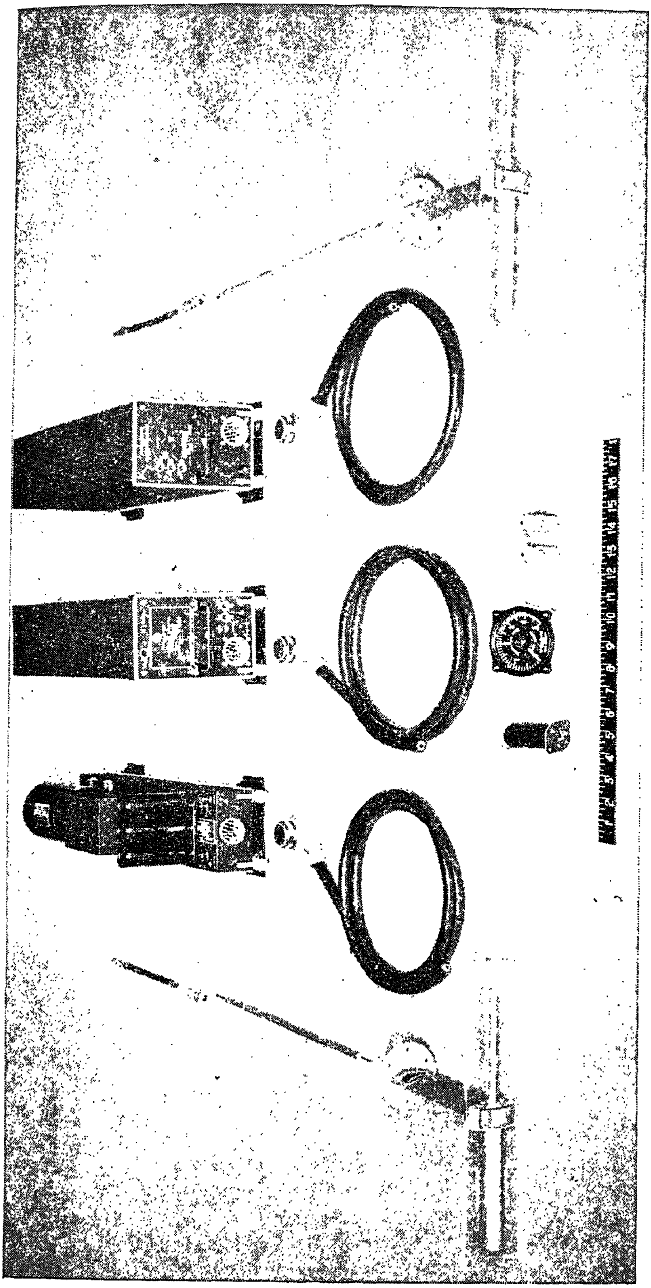


Figure 179. Systems Apparatus
(*Western Electric*)

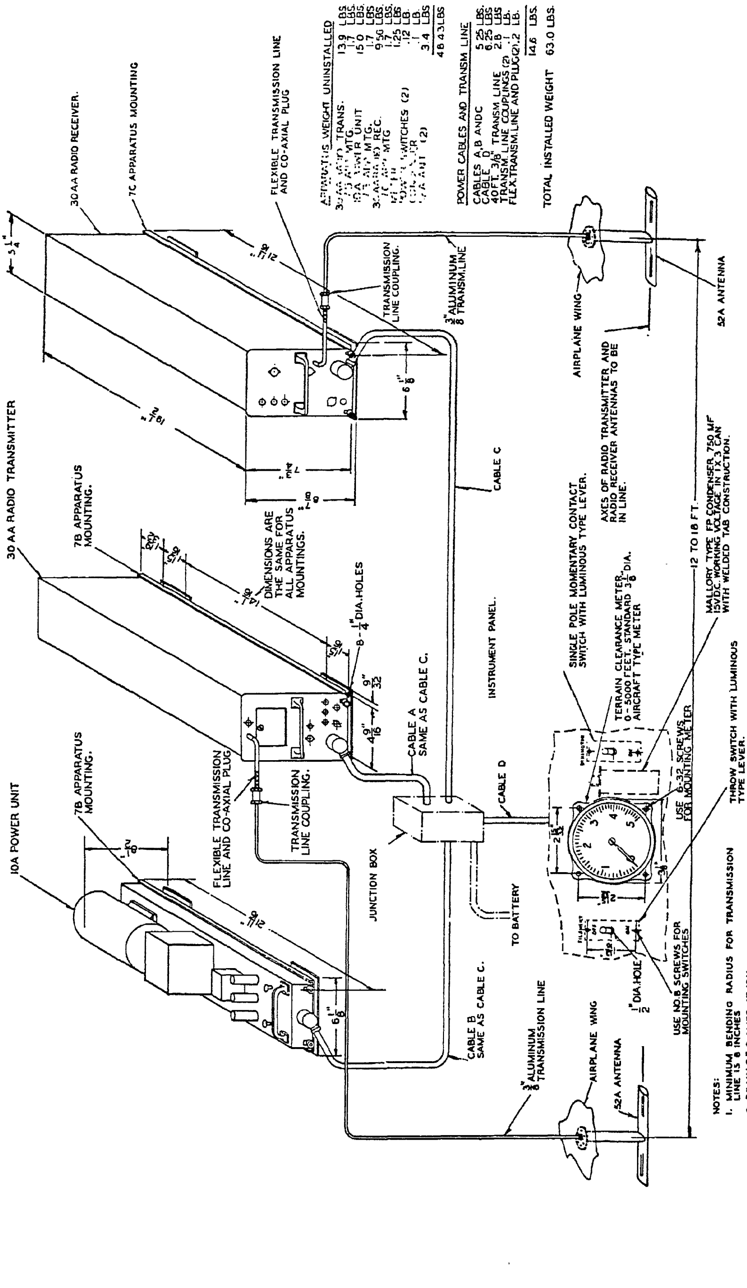


Figure 180. Outline Dimensional Drawing

In some installations it may be desirable to have the power switches mounted at some point in the cockpit other than the instrument panel. In this case the meter leads may be spliced onto the cable at that point. If this is done, however, the leads between the switch location and the meter should be shielded and the shield should be connected to the power shield at the point at which the splice is made and should be grounded to the instrument panel at the meter end of the pair.

CHAPTER 22

MAGNETIC COMPASS

In order thoroughly to understand the working principle of the magnetic compass it is well to become acquainted with magnets and magnetism.

Magnets. The magnets as used in the compass are small cobalt steel bars, each having a North and South pole. If a magnet is suspended from its center, one end will point directly to the earth's magnetic North pole and the other end to the magnetic South pole. The end which points to the magnetic North pole is called the North-seeking pole and the opposite end is called the South-seeking pole.

The earth is a large magnet having both a North and South pole. These magnetic poles are in the vicinity of the geographic North and South poles but do not coincide with them.

LAW OF MAGNETIC ATTRACTION AND REPULSION. Like poles will repel each other and unlike poles will attract.

VARIATION. Variation is the angular difference in degrees between the geographic North pole and the magnetic North pole. As shown in Figure 183, one line is marked 0° which means there is no variation and on flights along this line the compass reading is to be taken literally. All points east of the 0° line have a westerly variation and points west of the 0° line have an easterly variation.

DEVIATION. Steel parts, armament, electrical wiring, etc., in the aircraft will deflect the compass magnets from their true magnetic north-south alignment. This deflection in degrees is known as deviation and is inherent in all airplanes. A deviation card usually placed below the compass will show this error, which may be either easterly or westerly.

Use of the Compass

The compass indicates the heading of the aircraft with respect to magnetic north, establishes a fixed line of reference, permits the taking of cross bearings to determine track and position. The modern compass fulfills these requirements when properly compensated and correctly used by the pilot and navigator.

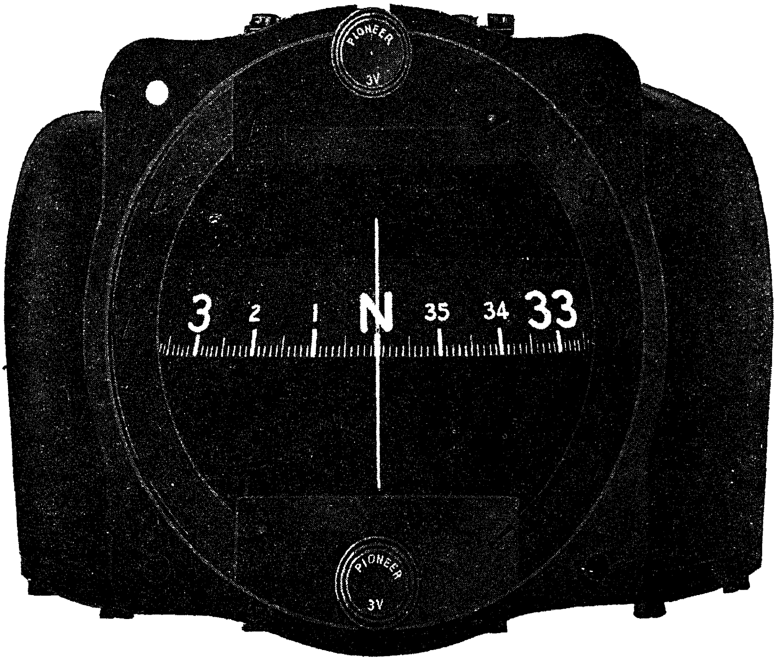
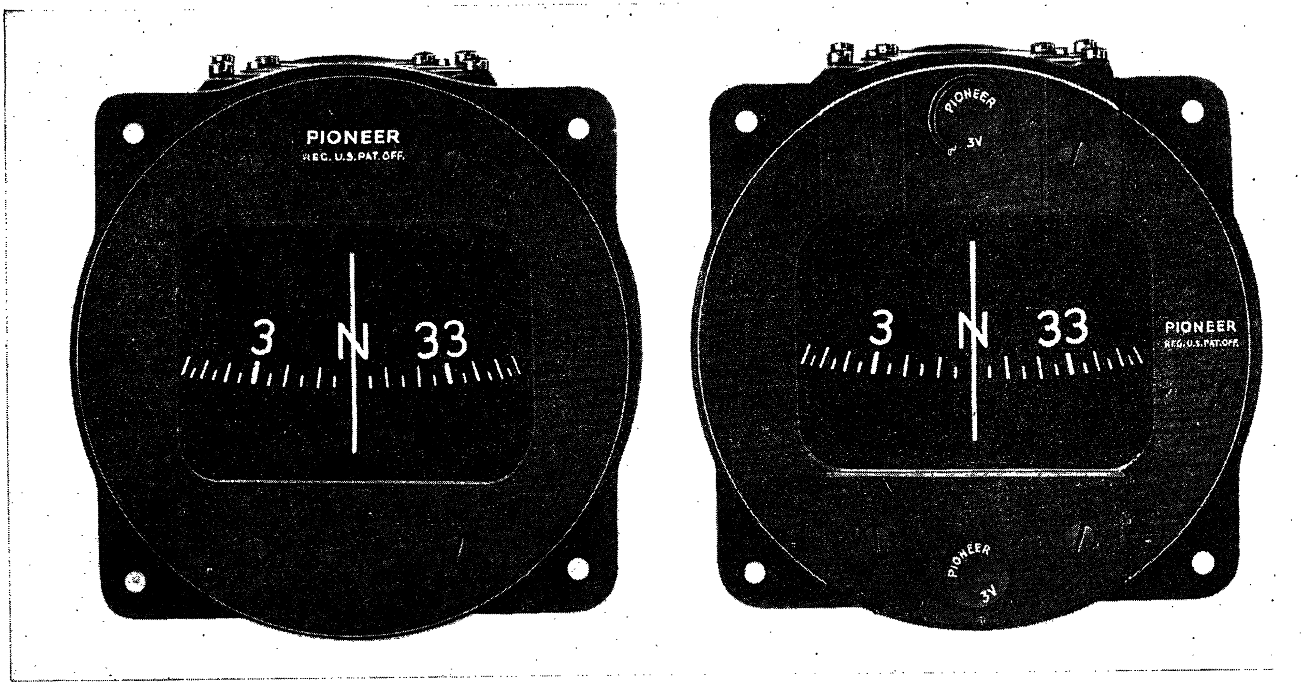


Figure 181. Pioneer Type 1814-1
(Pioneer Instrument Division of Bendix Aviation Corp.)

Flying with the Magnetic Compass

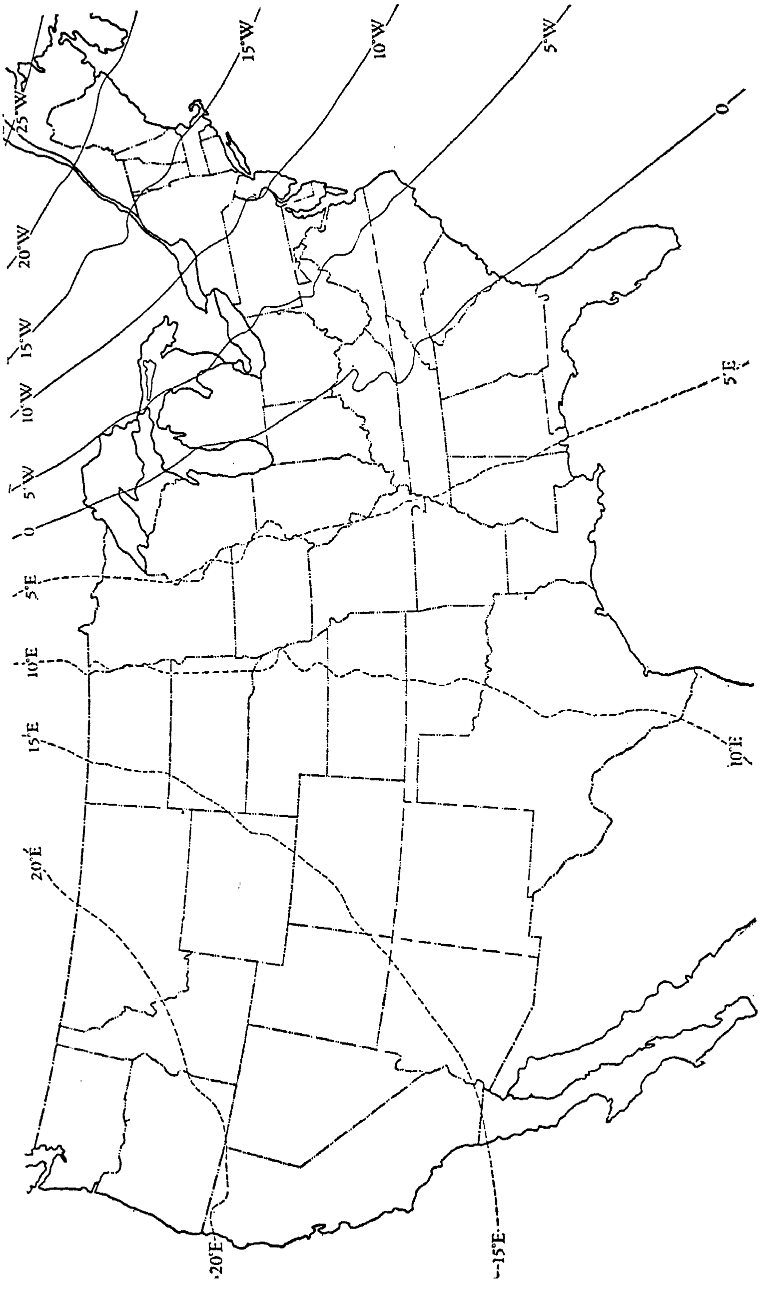
In order to plot a true course and be able to fly it, the pilot must be mindful of several ever present irregularities. To disregard these irregularities and attempt to fly by the actual reading of the compass will invariably cause the airplane to be



TYPE 1820-1

TYPE 1821-1

Figure 182. Pioneer Magnetic Compass
(Pioneer Instrument Division of Bendix Aviation Corp.)



Va

off-course. To understand and compensate for variation, deviation and wind drift will enable the pilot to fly a true course.

Variation differs in different localities as shown in Figure 183. Deviation, as previously explained, may be easterly or westerly and is seldom more than 5°, usually about 2°. Wind varies in direction at the various altitudes and obviously causes "drift" of the airplane.

Let us presume that we are at Yuma, Arizona, and want to fly to a town in the Middle West which is 45° as plotted on our map. Yuma has 15° easterly variation so we subtract the 15° leaving 30°. Upon consulting the compass deviation correction card we find that on the 45° heading there is an easterly deviation of 2°. We then subtract the 2° leaving 28°. Let us presume further that wind from the east is causing the airplane to drift 5°. We *add the 5° and fly a course of 33°.*

This degree heading will hold good unless the wind increases or decreases in velocity or the airplane is flown at a different altitude, where wind from a different direction might be encountered. In the beginning, by far the best practice is to check and double-check relying, when visibility permits, on familiar ground objects. If you are unsure of your position, locate a main highway or railroad track and follow it to the next town.

Operation of Kollsman Type 464

The magnetic compass consists essentially of a graduated card (A) bearing a system of parallel magnets (B and B_1) so suspended within the container (C) as to be free to assume the direction of the meridian determined by the earth's magnetic field. The indications of the card are read against a reference line (D) called the lubber's line which represents the longitudinal axis of the airplane when the compass has been installed. A projection of this line onto the compass card gives the magnetic heading of the aircraft.

The card and magnets are attached to the float (E) which contains a hardened steel pivot (F). The pivot rests on a cup jewel (G) contained in the jewel post (H) and supported by the jewel post support (I). A spring (J) on the jewel post absorbs any external vibration.

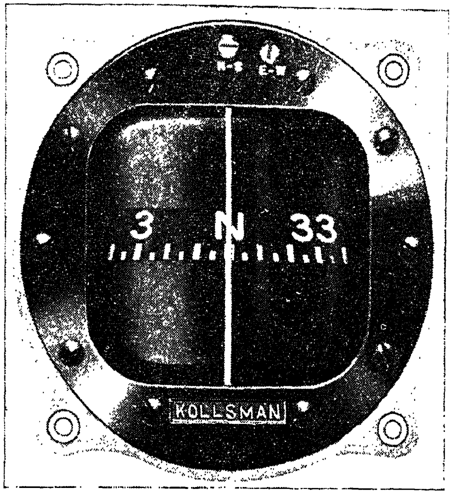


Figure 184. Kollsman Type 464

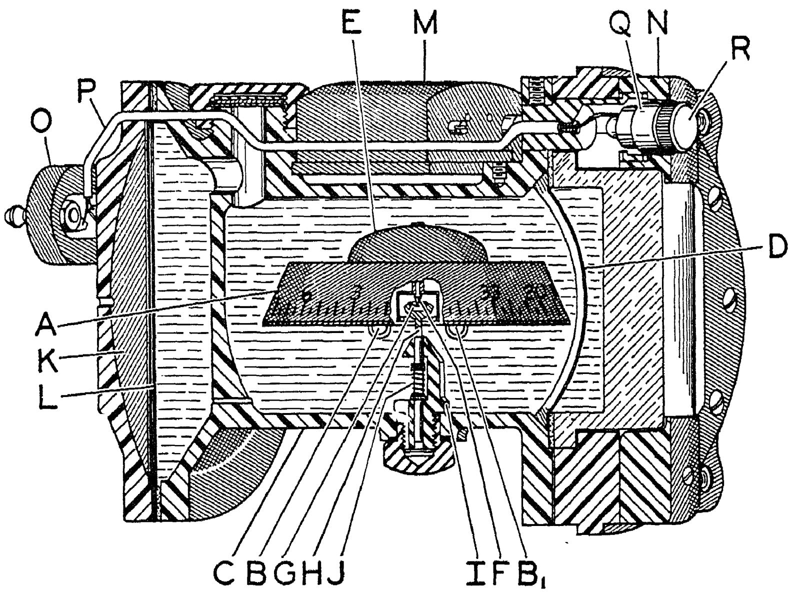


Figure 185. Schematic Drawing Kollsman Type 464
(Kollsman Instrument Division of Square D Co.)

An expansion chamber (K) is divided by a flexible diaphragm (L) which allows the filling liquid to expand or contract with temperature changes.

A compensator (M) provides the means for correcting for magnetic interference. On the model shown, the compensator is adjustable by screws found under the light shield (N).

When the compass is provided with a light, connections are made at the plug (O) from which the shielded leads (P) run to the socket (Q) into which is screwed the 3-volt lamp (R).

Operation of Kollsman Type 398C

The direction indicator consists of a magnet and float assembly (A), a magnetic pick-up element (F), a right angle gear drive (G), and a pointer (M). The directive magnet and pivot (not shown) are contained in the float which rests upon a jewel in the supporting post (N).

Damping vanes or fins (C) which protrude radially from the shell of the float provide damping without circulating the entire mass of the liquid.

The upper half (D) of the bowl is left partly empty so that the liquid may expand or contract with temperature changes while a baffle plate (E) prevents movement of the upper liquid from being transmitted to that in the lower bowl (B).

The pointer is operated in conjunction with the magnetic element (F) by a right angle gear drive (G).

The reference index and parallel lines (O) are operated by the adjustment knob (H) through gear train (I). Compensator adjustment is accomplished by turning shaft (J) (cut off) through gear train (K) to compensator (L).

Operation of Pioneer Type 1809-1A

Compasses of the aperiodic type (Figure 188) function with no appreciable overswing. The balance between damping and magnetic strength is so maintained that the magnet assembly returns to its heading slowly and positively and does not oscillate about the point of heading. One of the salient features is

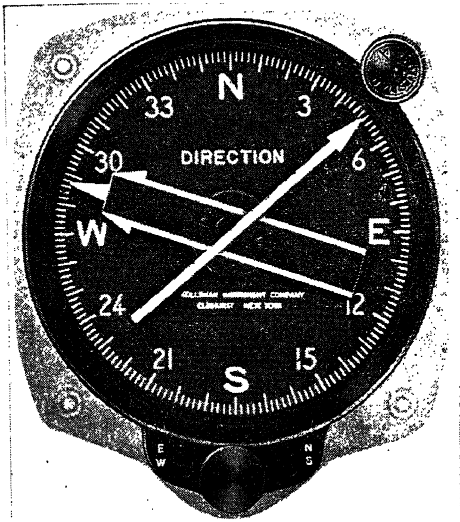


Figure 186. Kollsman Direction Indicator Type 398C

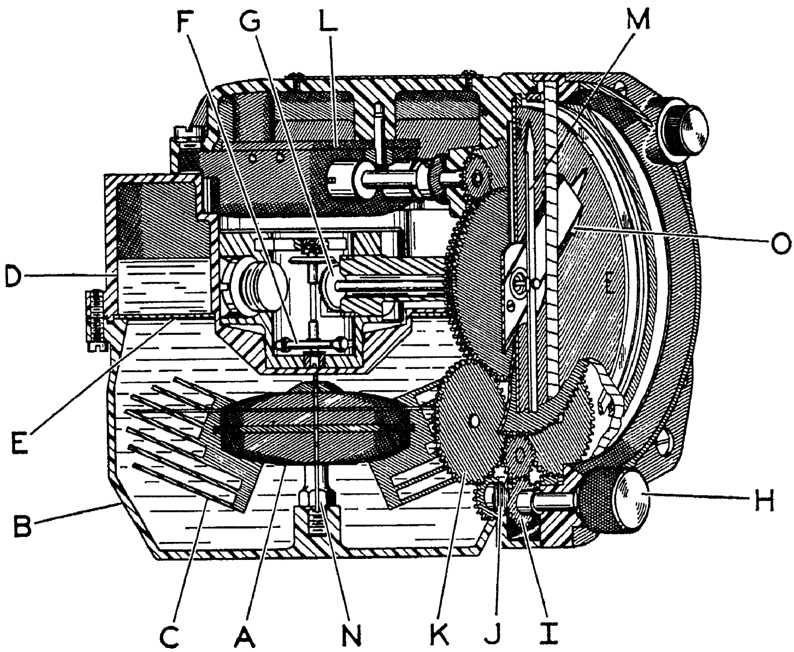


Figure 187. Schematic Drawing—Kollsman Direction Indicator Type 398C
(Kollsman Instrument Division of Square D Co.)

the freedom from turning and acceleration errors in straight flight. The card is damped as regards rotation away from the horizontal position so that it does not tip on yaws, bumps, or other irregularities encountered in ostensibly straight flight in rough air.

The magnet and float assembly carries one long radium-painted arrow which can be readily aligned with the radium-painted index line mounted inside the compass bowl. This vertical index line is curved to the path of the arrow so that the clearance between the arrow on the magnet assembly and the index line remains constant even in bank and climbs as long as the arrow is aligned with the index marker, thus removing the possibility of parallax error.

The compass bowl, which carries the radium-painted index line, is integral with the rotatable azimuth circle. In using the compass, the lockscrew is loosened and the azimuth circle rotated until the desired course is indicated by the lubber's line on the forward end of the instrument. The lockscrew is then tightened and as the airplane comes into its heading, the arrow on the card will align with the index line.

Test Specifications

When it is observed during a flight that the compass is in error it should be removed from the airplane and shop tested. In order to facilitate this procedure the following test specifications for the Pioneer Type 1814-1 are listed. These specifications apply only to this type and the correct specifications should be at hand for all other types and makes.

Whenever the pressure, temperature, and magnetic field strength existing at the time of the test are not specified definitely, it is understood that the test is to be made at room temperature (approximately plus 20° C.), in a horizontal field strength of approximately 0.18 gauss, and a vertical field strength of approximately 0.54 gauss in the direction normal in the Northern Hemisphere. When tests are made with room temperature, or magnetic field strength differing materially from the above values, proper allowance shall be made for the differ-

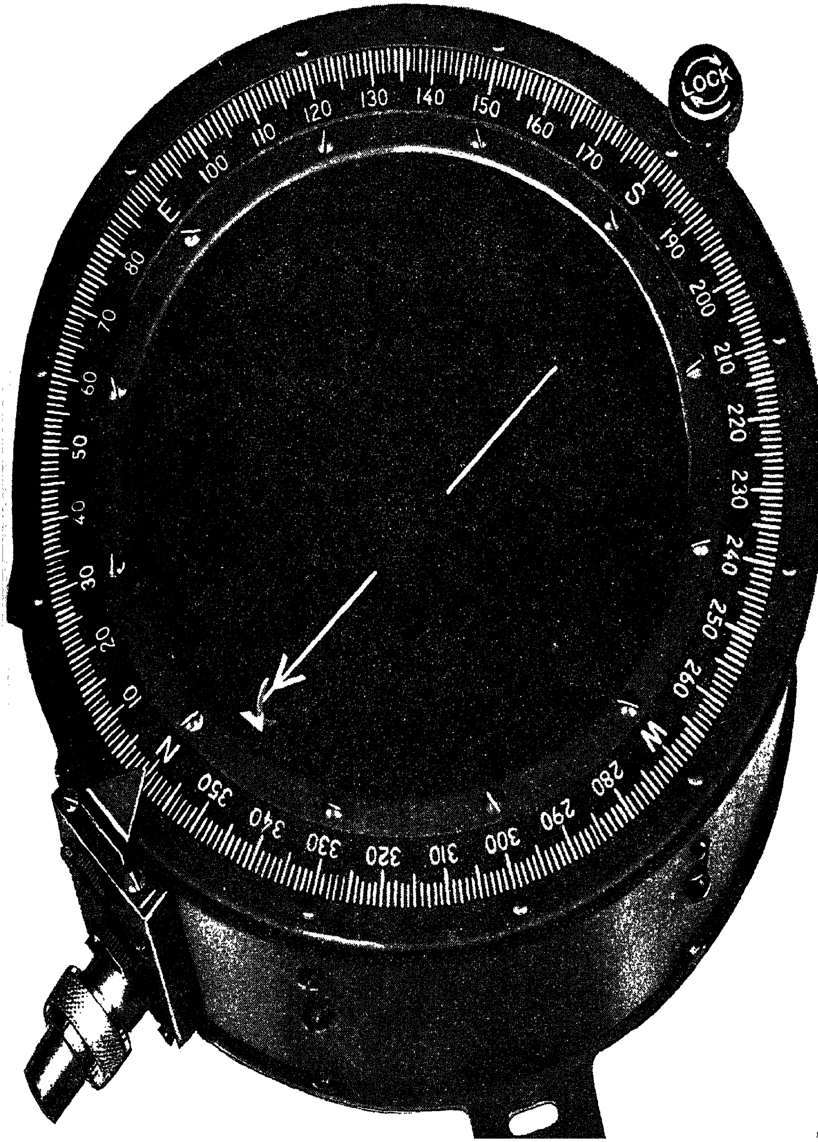


Figure 188. Pioneer Navigation Compass Type 1809-1A
(Pioneer Instrument Division of Bendix Aviation Corp.)

ence from the specified conditions. Unless otherwise specified, the instrument shall be tapped lightly before taking readings.

Card Error. The compensator shall be removed and the compass mounted on a standard turn table with its mounting face at right angles to the magnetic meridian (or its fore and aft line parallel to the magnetic meridian). The card error shall then be determined at the 0° setting and successively at the 90°, 180°, and 270° settings. At the discretion of the operator, the errors may be determined at any intermediate settings. The card error at any setting shall not exceed 1°.

Compass Error. With the compensator mounted in place and the N-S and E-W compensating systems set at their minimum effect adjustments, the errors determined as in the preceding paragraph shall not exceed 3°.

Friction Error. After the card has been deflected from its position of rest, either way, by 5°, it shall return to its original position without vibration within ½°.

Balance. The card shall balance on its pivot so that the plane of the card is horizontal within 2°.

Damping. The damping shall be measured with the compass in a normal upright position on any heading. The test is to be made at room temperature, approximately 20° C. Using a small magnet, the card is to be deflected from its heading through an angle of 30°. After suddenly removing the magnet the average time required for the card to pass through an angle of 25° for both right and left deflections shall not be more than 3.6 seconds nor less than 3.0 seconds. The card shall not overswing its original heading by more than 15 degrees.

Heeling. When the compass is tilted from its normal upright position to any position within an angle of 20°, the card shall be perfectly free to revolve in its pivot. When viewed from the normal observation position, the card shall be visible at all times during this test.

Compensator Test. With either the N-S or E-W compensating system set at its minimum effect and the compass on the corresponding heading, the compensator shall have no effect on the card. With either the N-S or E-W compensating system adjusted for its maximum effect, the compensation effect shall be not less than 20°. Maximum compensation applied on the opposite compensating system when the compass is on any of the four cardinal headings shall not affect the indication by more than 3°.

Lighting. With 12 volts applied to the lighting system, the illumination shall be satisfactory.

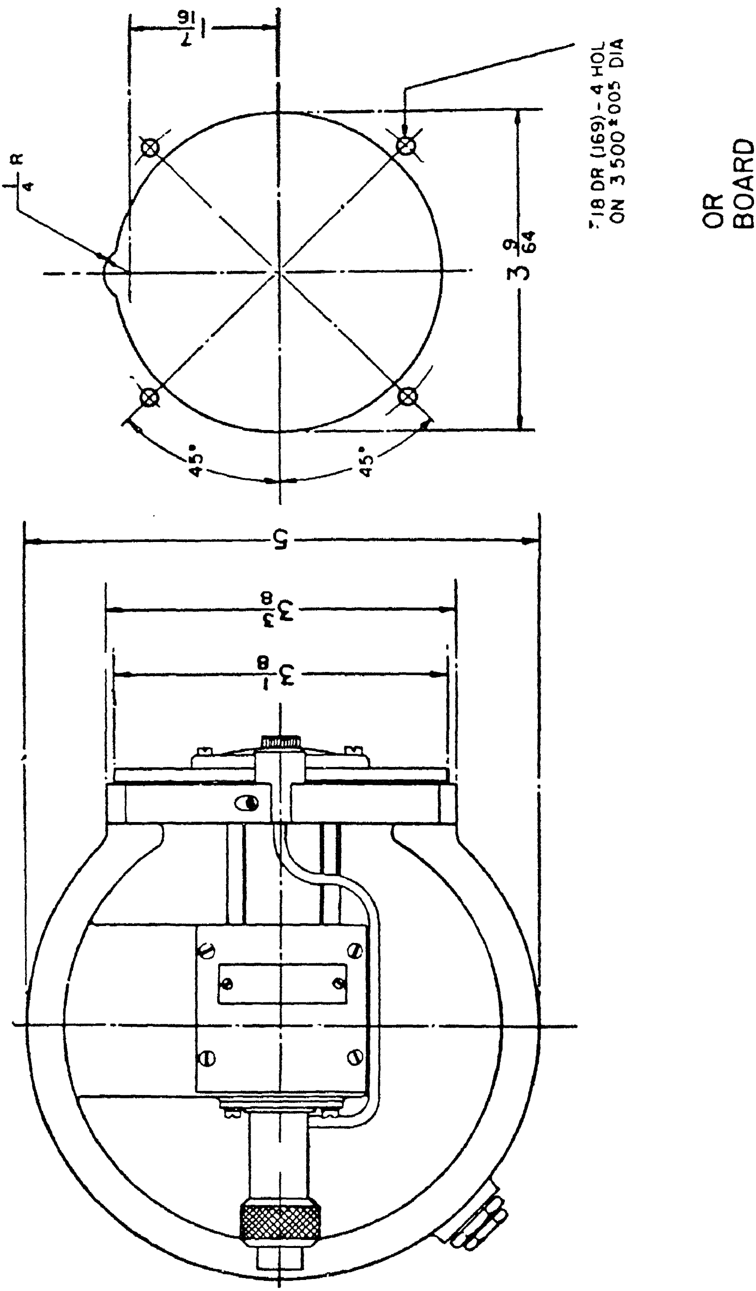
Insulation Breakdown. 550 volts at a commercial frequency shall be applied between each terminal and the ground for a period of one minute without a breakdown in insulation.

Installation

To install the above type cut a standard 3 9/64″ hole in the instrument panel. Mount the instrument from the rear into the panel and secure with the proper screws. The compass face should be vertical when the airplane is in level flying position. If the compass is mounted in a separate panel, the panel should be of nonmagnetic material (dural, brass, etc.) and be so located that it will be far enough from steel or magnetic members. Possibly the best location may be determined by moving the compass about and noting the card deflection.

The deviation correction card should be mounted directly under the compass or in a convenient location for the pilot.

Electrical lighting connections are made to a plug at the rear of the instrument. A resistor limits the 12- or 24-volt current to 3 volts at the bulb. All other wiring should be kept at a distance. The electrical equipment of nearby apparatus should be switched on and off and the deflection of the compass noted. If the wiring is at fault it should be rearranged. If the deflection is no more than 25° the condition may be corrected with the compensating magnets marked E-W, N-S which are accessible at the front of the instrument. These compensating


7/16
R 1/4
.18 DR (.169) - 4 HOL
ON 3.500±.005 DIA
3 9/64
45°
45°
5
3 3/8
3 1/8
OR
BOARD

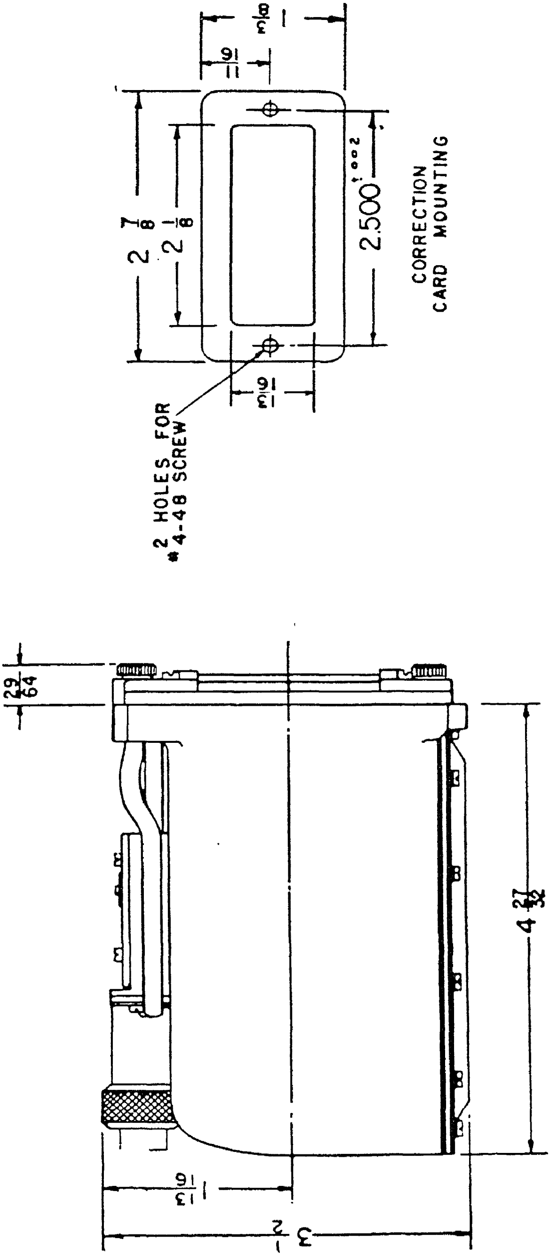
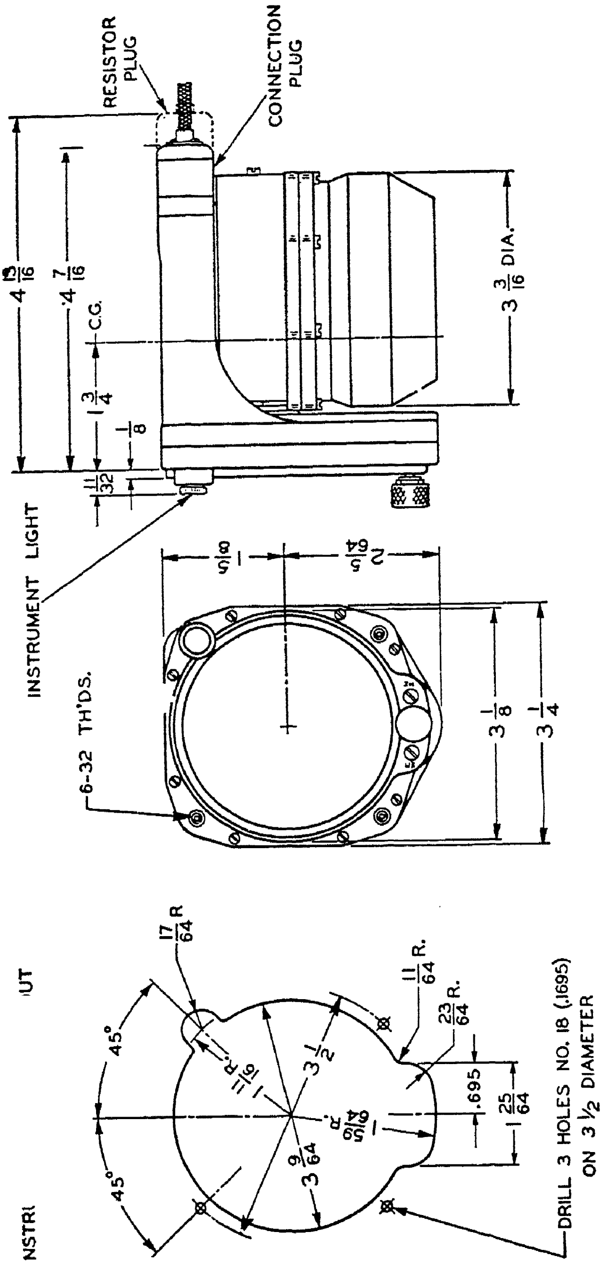


Figure 189. Installation Drawing of Pioneer Type 1814-1
(Pioneer Instrument Division of Bendix Aviation Corp.)



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magnets employ two sets of magnets arranged in a horizontal plane. The best results are obtained with the least amount of compensation.

Pioneer Demagnetizing Coil

From time to time, airplanes are encountered which have highly magnetized steel fuselage members which make the compensation of a compass practically impossible. To offset this difficulty, the demagnetizing coil has been developed.

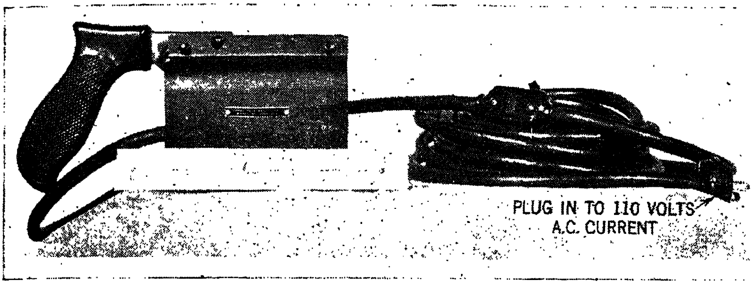


Figure 191. Pioneer Demagnetizing Coil
(Pioneer Instrument Division of Bendix Aviation Corp.)

It must be remembered that a piece of iron or steel may affect a compass even though it is not magnetized at all. One way that such a part may affect a nearby compass is by providing an easy path for the earth's magnetic flux. When the member is at 45° to the North-South line, part of the earth's flux will be deflected and will pass through the member. A compass nearby will take a position between the direction of the member and the North-South line. When the member is in line with, or at right angles to, the North-South, there is no deflection of flux. Since these errors occur every 90°, they are known as quadrantal effect. A piece of iron or steel which is not magnetized and does not have a shape which tends to produce quadrantal errors may still affect the compass by induced magnetism. In this case, the compass magnets induce a magnetism in the part so that there is a reaction which affects the compass reading. The demagnetizing coil cannot remove the effects just

mentioned. However, unless the compass is mounted in very close proximity to a steel member, the largest part of deviation is due to magnetized structure.

This apparatus consists of a great number of turns of wire on a laminated steel core provided with a pistol grip handle and a 15-foot connecting cable with switch and plug. When attached to 110 volts alternating current, this coil produces a rapidly reversing magnetic field which, when properly applied, will remove practically all of the magnetism existent in a steel member.

Before using the coil, all material which uses permanent magnets should be removed at least 2 feet from the locality to be demagnetized. This includes magnetic compasses, magnetos, generators, and electrical instruments. The coil should then be plugged in to 110 volts alternating current, and slowly brought up to the structure to be demagnetized. After slowly rubbing all of the affected structure, the coil should be slowly withdrawn. It is very important that the circuit through the coil not be broken at any time when the coil is near the plane. The circuit may be broken at the peak of an alternating current wave when current flow is at a maximum in one direction. This will magnetize rather than demagnetize.

"Swinging" the Compass

Every compass installed in an airplane is subject to magnetic deviation, caused principally by the semi-permanent magnetism of the plane. Because of this, compensation is necessary before any attempt is made to use the compass for directional indication. The pelorus or magnetic azimuth is used in connection with the swinging of the plane necessary to compensation.

This apparatus consists of a rotatable brass disc with an engraved azimuth circle together with locking and leveling devices. A rotatable device is superimposed upon this disc, consisting of an inclosed compass needle and two sighting vanes. The instrument is also fitted with a device for attachment to a wooden tripod.

To determine magnetic compass directions, proceed as follows:

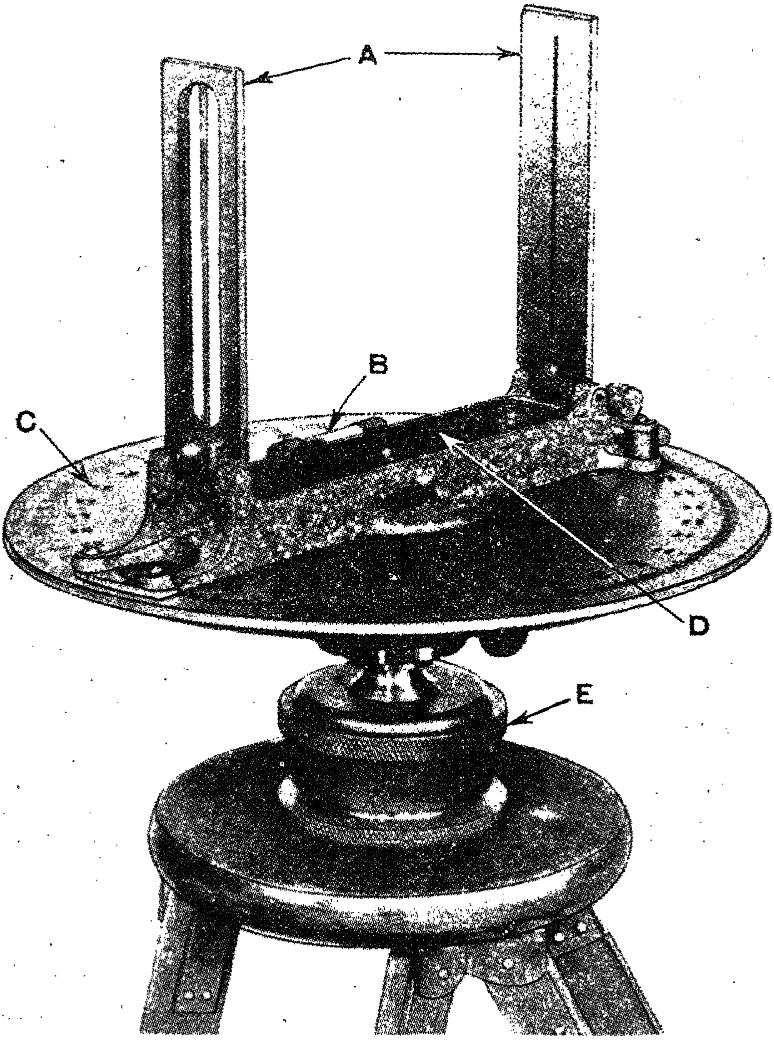


Figure 192. Pioneer Pelorus
(Pioneer Instrument Division of Bendix Aviation Corp.)

A—Sighting Vanes
B—Bubble Level
C—Azimuth Circle in Degrees
D—Magnetic Needle
E—Knurled Knob

(a) Set the pelorus on its tripod in a position on the field well away from the plane, hangars or anything apt to distort the magnetic field.

(b) Level the base plate by means of the small bubble levels attached to the needle case, and then lift the two sighting vanes. Free the magnetic needle by lifting the locking lever, and rotate the case until needle aligns with reference marks under glass cover. The south end of the needle is wrapped with brass wire. This will establish the true magnetic north. Leaving the case in this position, loosen knurled knob under the base and rotate the plate until the reference mark at the extreme north end of the needle case is on zero. Lock the plate in this position by tightening the knurled knob.

(c) Leaving the plate locked, rotate the sighting vanes on needle case until when sighting through the slit vane, the wire on other vane is directly toward some object discernible at as great a distance as possible, such as a smoke stack, water tank, etc. Take a reading on the base plate of the number of degrees this position bears from north, and make a note of this reading. This completes the first step. and is known as "setting up" the pelorus.

(d) Now bring the plane out to approximately the same spot at which the pelorus was set up and elevate the tail on a dolly to flying position. Securely mount the pelorus on its tripod coincident with the center line of the plane, and on the cowling or top of the wing. Level the plate as before by means of the bubble levels. Rotate the sighting vanes until the wire on vane is directly on the tail fin when sighting through the slit vane. If plane has multiple rudders, sight directly over some point in the center of the epenage.

(e) Leave the vanes in this position and rotate base plate until the zero mark is coincident with the mark at extremity of needle case and towards the nose of the plane.

(f) Lock plate by the knurled knob. Now set the vanes at the position noted as the bearing off north of the object sighted on when reading was taken on the ground. Swing the tail of the plane until the same sighted object is exactly on the wire when sighted through the slit vane.

From this point, directions are determined by simply setting the sighting vanes at the desired direction on the base plate and swinging the plane until the same sighted object is directly on the wire.

DATE OF SWINGING............BY............													
	N			W			S			E			N
FOR	360	330	300	270	240	210	180	150	120	90	60	30	0
STEER													
DEV.													

Figure 193. Compass Correction Card

The airplane is first headed true north (magnetic) and the full compass error removed by turning the N-S screw using a screwdriver of nonmagnetic material. The ship is then headed due east (magnetic) and again the full compass error is removed by adjusting the E-W screw. Next, the ship is headed due south (magnetic) and only one-half the compass error is removed by turning the N-S screw. Similarly, the ship is then headed due west (magnetic) and again one-half the compass error is removed, by turning the E-W screw. The compass is then fully compensated. The ship should next be swung to each successive 30° heading and a table of compass deviations noted on the correction card supplied with the instrument. The correction card (Figure 193) should be mounted adjacent to the compass in the clear view of the pilot.

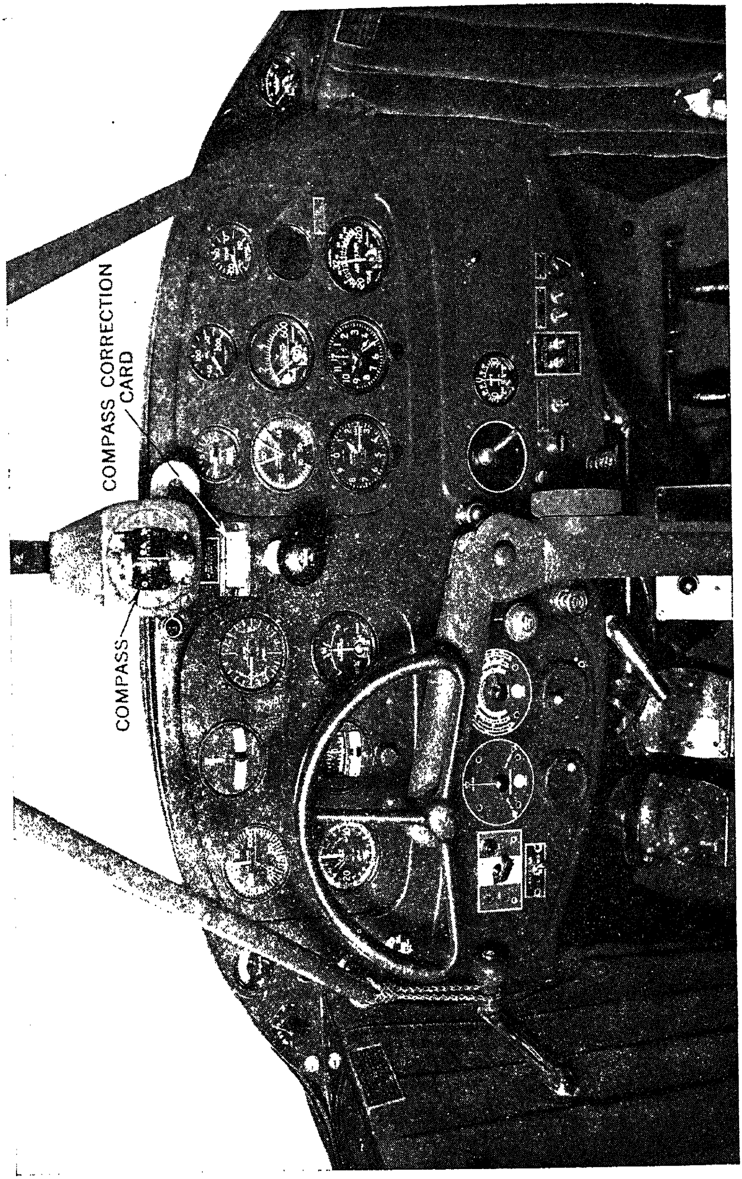


Figure 194. The Beechcraft D17 Instrument Panel Shows a Well-Balanced Layout
(Beech Aircraft Corp.)

CHAPTER 23

KOLLSMAN DIRECTION INDICATOR

(Remote Indicating)

The Kollsman remote indicating compass provides an accurate continuous indication of the heading of the aircraft with respect to magnetic north. A master compass is mounted at some convenient place in the airplane where it will be comparatively free from magnetic interferences. Indicators are situated at convenient places in the cockpit and in the navigator's room. For aerial photography one indicator may be placed in the camera.

The features of this type of remote indicating compass are:

(a) A means of placing the magnetic compass in a favorable position and still have indication at the instrument panel.
(b) The ability to place the compass indicator in the best position in the flight group without regard to local magnetic interference (deviation).
(c) A magnetic compass with several indicators.
(d) Vertical dial indicators.
(e) Desirable features of both navigator's and pilot's compasses combined in one instrument.
(f) A means of placing a magnetic indication in an aerial camera.

The schematic view of the master compass (Figure 197) will help in understanding the basic principle of operation. The liquid is contained in a bowl or chamber made up of two parts, both of which are of bakelite. These parts are screwed together with a lead gasket interposed so that no liquid may escape. The magnet and float assembly is mounted in the lower part of the bowl. A pivot is contained in the float which rests upon a jewel in the supporting post. The customary spring suspension of the jewel post prevents damage to the pivot during rough usage.

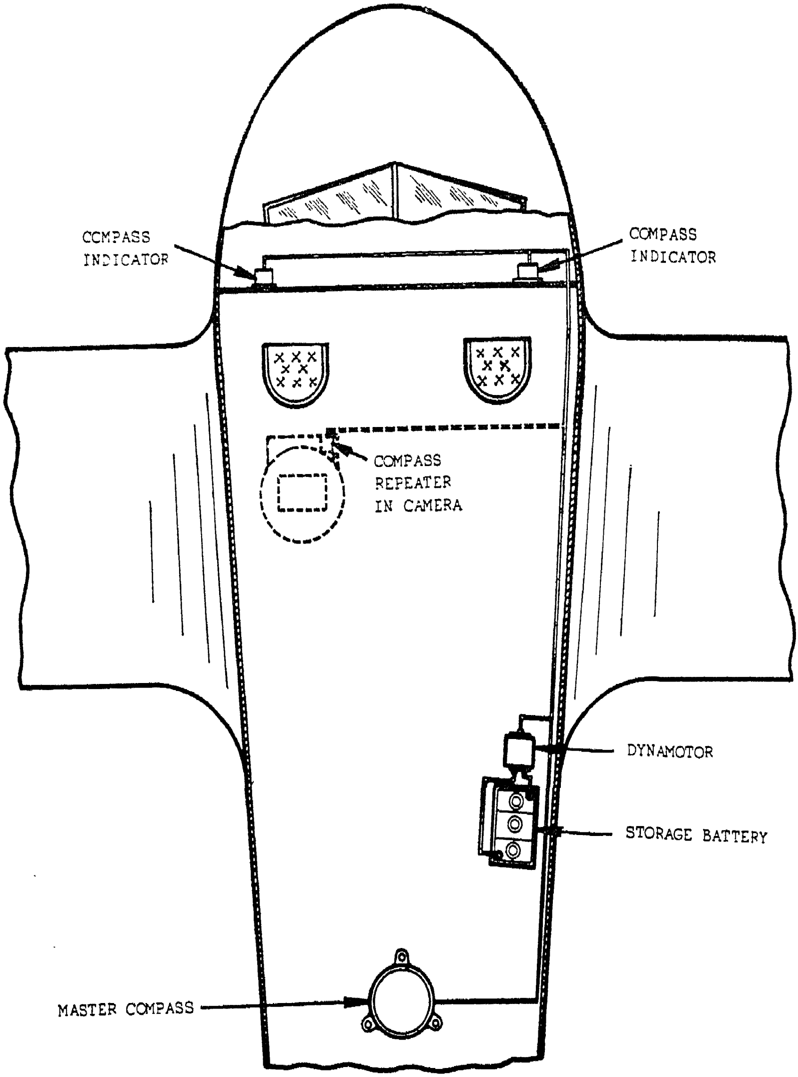


Figure 195. Schematic View of a Kollsman Remote Compass Installation
(Kollsman Instrument Division of Square D Co.)

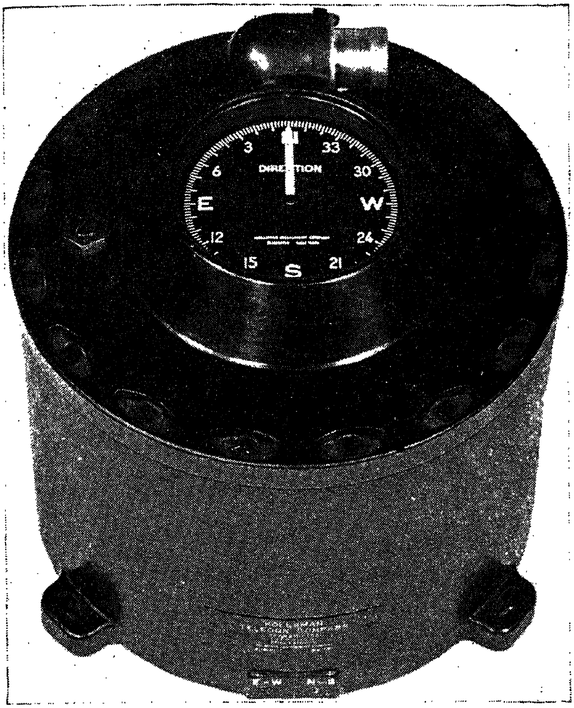


Figure 196. Master Compass Type 467
(Kollsman Instrument Division of Square D Co.)

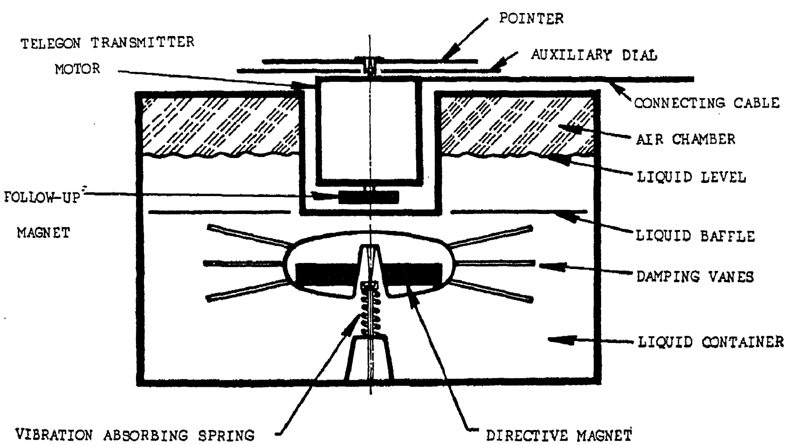


Figure 197. Schematic View of the Master Compass

The directive magnet, placed inside the float, is made of high strength alloy steel and provides more than sufficient torque to operate the Telegon transmitter motor and three repeaters.

Damping vanes or fins protrude radially from the shell of the float.

A baffle plate is used which has sufficient openings to permit passage of the liquid to or from the upper chamber but which does not permit movement of the upper liquid to be transmitted to that in the lower bowl. The upper part is left partly empty so that the liquid may expand or contract with temperature changes, thereby eliminating expansion diaphragms. Deaerating of the liquid when filling, to prevent bubble formation, is not necessary.

The rotor of the Telegon transmitter motor is operated in conjunction with the magnetic element of the compass by a magnetic coupling. A small magnet, mounted on the lower end of the rotor shaft follows the magnetic element, thus making possible the transmission of motion through the compass bowl without having any direct mechanism connection. Jeweled bearings are used in the motor to reduce friction.

Flying with the Direction Indicator

The dial, Figure 198, is fixed and the numbers are always in the same position; consequently, they become fixed in the pilot's mind. The reference index and parallel lines are moved manually, by the lower setting knob, to any desired heading. The pointer, as mentioned before, indicates the magnetic heading of the airplane. As shown, the reference index and parallel lines indicate a 287° heading while the pointer indicates a 49° heading. Let us presume that the airplane is in flight and the pilot wishes to continue on a 49° heading. By rotating the lower setting knob the reference index is brought around clockwise until it coincides with the pointer. The parallel lines then rest on either side of the pointer shaft. The pilot is then relieved of the strain of trying to hold the pointer on the 49° mark on the dial. So long as the pointer coincides with the reference index and the pointer shaft lies parallel in the center of the parallel lines the 49° heading will be maintained.

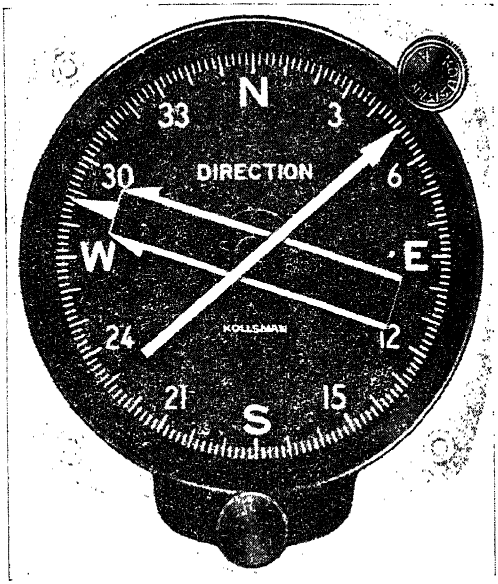


Figure 198. Direction Indicator Type 465 SD
(Kollsman Instrument Division of Square D Co.)

If the pilot wishes to fly a 287° heading the reference index and parallel lines are rotated to the position shown in Figure 198. The airplane heading is then altered until the pointer coincides with the reference index. This procedure holds true for all headings.

Telegon Remote Indicating System

Basically the Kollsman Telegon system of remote indication uses the well-known principle of the self-synchronizing electric motor. When two such motors are connected and energized by a proper source of alternating current, their rotors will always remain in exactly the same angular position with respect to their stators. Thus, if the rotor of one motor is moved by an outside force, the rotor of the other will follow automatically.

For compass indication, the motor in the indicating instrument carries a compass dial and a pointer attached to the rotor

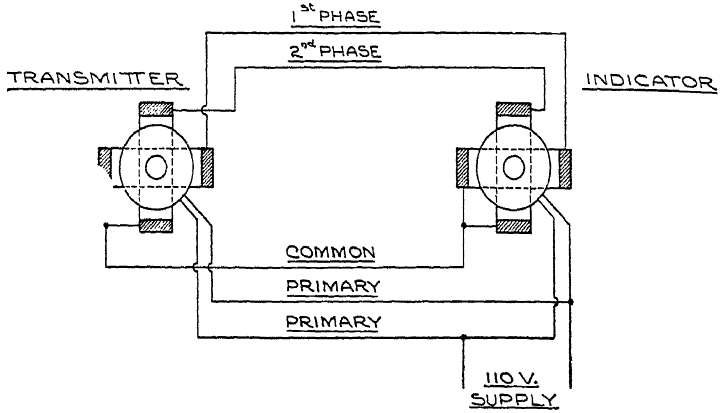


Figure 199. Schematic Wiring Diagram of Telegon Units

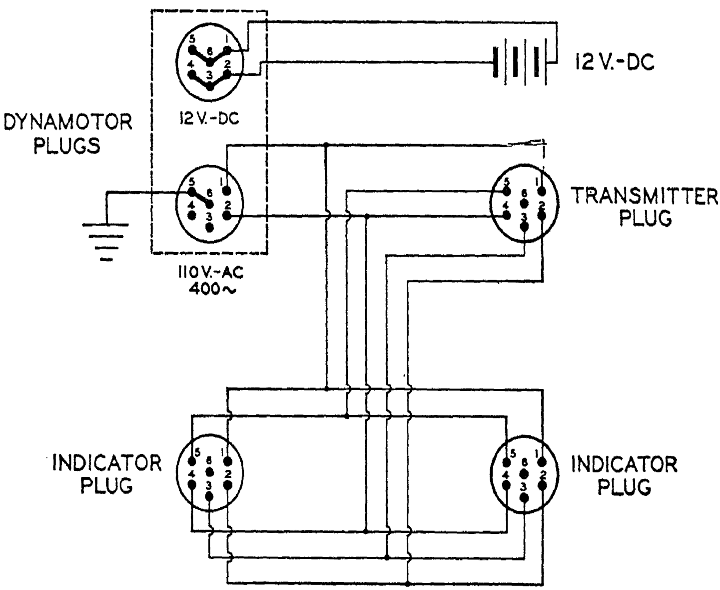


Figure 200. Actual Wiring Diagram of Typical Installation Using Two Compass Indicators

shaft. Movements of the rotor in the master compass unit are therefore faithfully transmitted to the pointer of the indicator.

The accuracy of the Telegon system is inherent. Self-synchronous motors cannot lose their phase relationship unless they are completely inoperative. There are no errors due to temperature changes.

The Telegon motors used in both indicators and transmitters are similar in construction, differing only in the direction of winding. Each motor draws 1.25 watts. Standard units operate on single phase alternating current of 110 volts at 400 cycles.

Source of Supply. The Telegon motors are energized by 400 cycle, AC, single phase, 110-volt supply. When such a supply is available on the larger airplanes, no auxiliary equipment is necessary. For smaller airplanes, operating on 12- or 24-volt storage batteries, a very small dynamotor (generator) is required. These dynamotors are small editions of standard units.

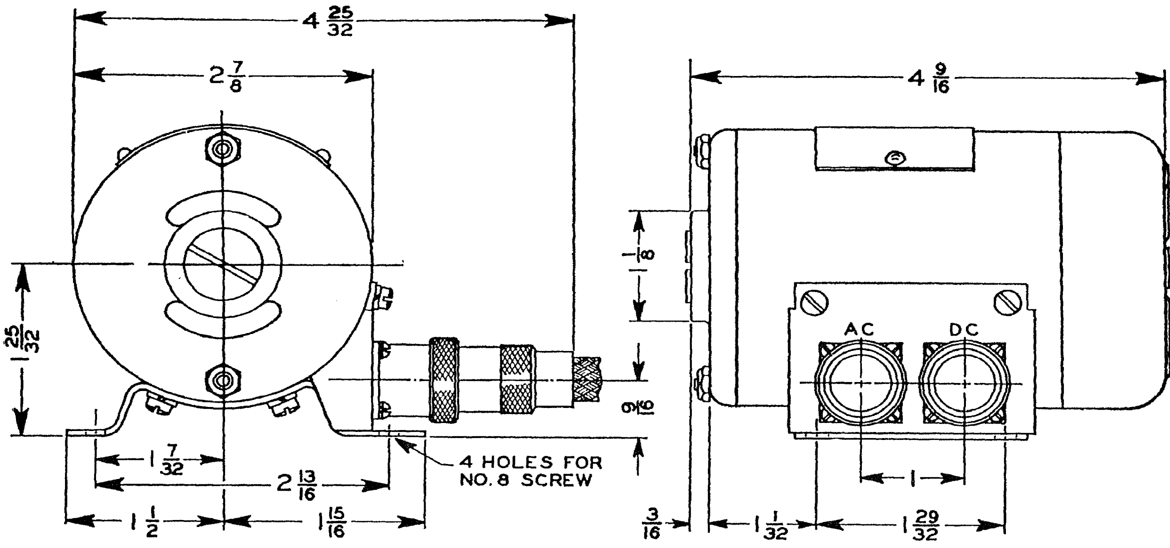
Installations. The schematic view, Figure 195, shows the relative simplicity of the installation of a typical remote compass installation. A five conductor cable of #22 American wire gauge (0.0253) insulated copper wire connects the various units. Aside from the selection of a magnetically free position for the master compass, no special precautions are necessary. Screw plugs are provided so cable may be quickly attached.

The master compass is compensated in the same manner as other compasses. In the event that a magnetically free position cannot be located for the master compass, a relatively close compensation may be obtained with the Poly-Plane compensator shown at the base of the instrument, Figure 196. A correction card mounted near the indicator on the instrument panel informs the pilot of the deviation errors.

Wiring Diagrams

Figure 199 is a schematic wiring diagram of Telegon units. It shows method of connecting one indicator to one transmitter.

Figure 200 shows the actual wiring diagram of a typical installation using two compass indicators.



TYPE	MOTOR			ALTERNATOR			
411	VOLTAGE	24 V. - DC	SPEED	FREQUENCY	CURRENT	VOLTAGE	CAPACITY
	START	2 AMPS	4000 RPM	400~ ±10%	.086 AMPS	110 V.-AC	3 TELEGON UNITS
	FULL LOAD RUNNING	1.0 AMPS					
421	VOLTAGE	12 V. - DC	4000 RPM	400~ ±10%	.086 AMPS	110 V.-AC	3 TELEGON UNITS
	START	6.5 AMPS					
	FULL LOAD RUNNING	2.1 AMPS					

DC PLUG CONNECTIONS: POSITIVE - 2, 3 & 4, NEGATIVE - 1, 5 & 6
AC PLUG CONNECTIONS: OUTPUT - 1 & 2, GROUNDED - 5 & 6

Figure 201. Installation Dimensions of Dynamotor and Electrical DC and AC Plug Connections

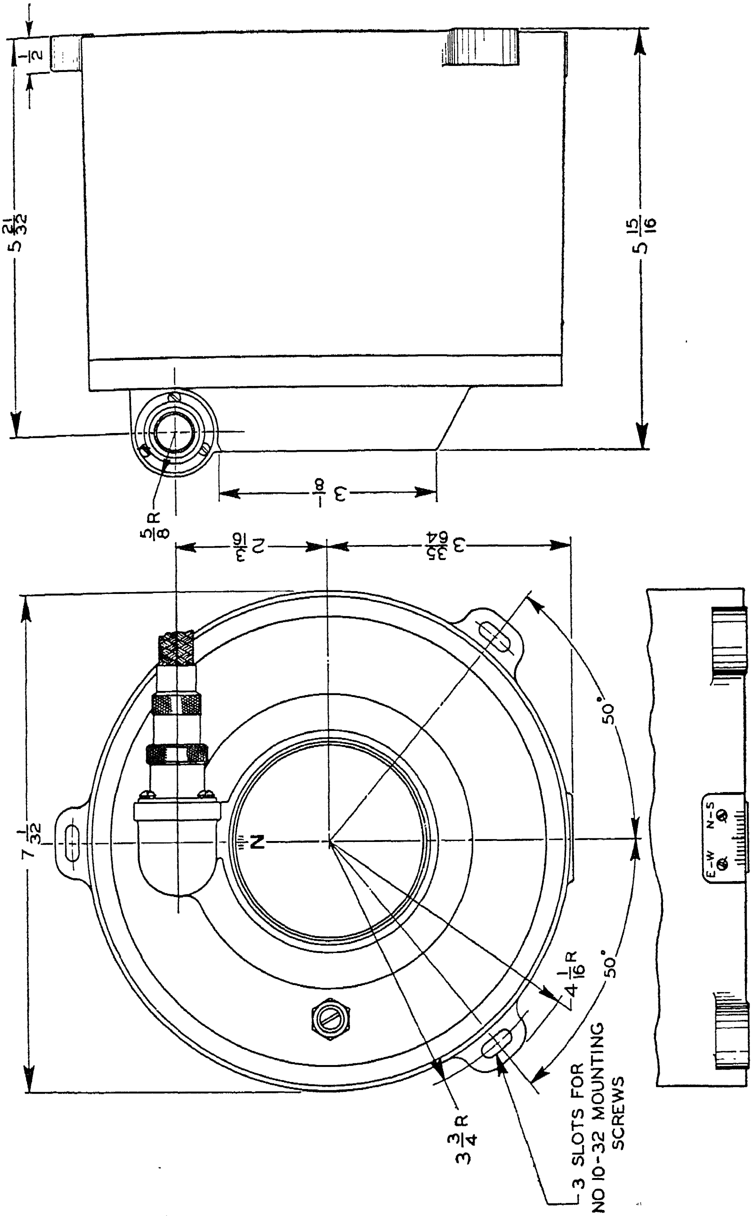


Figure 202. Installation Dimensions—Master Compass

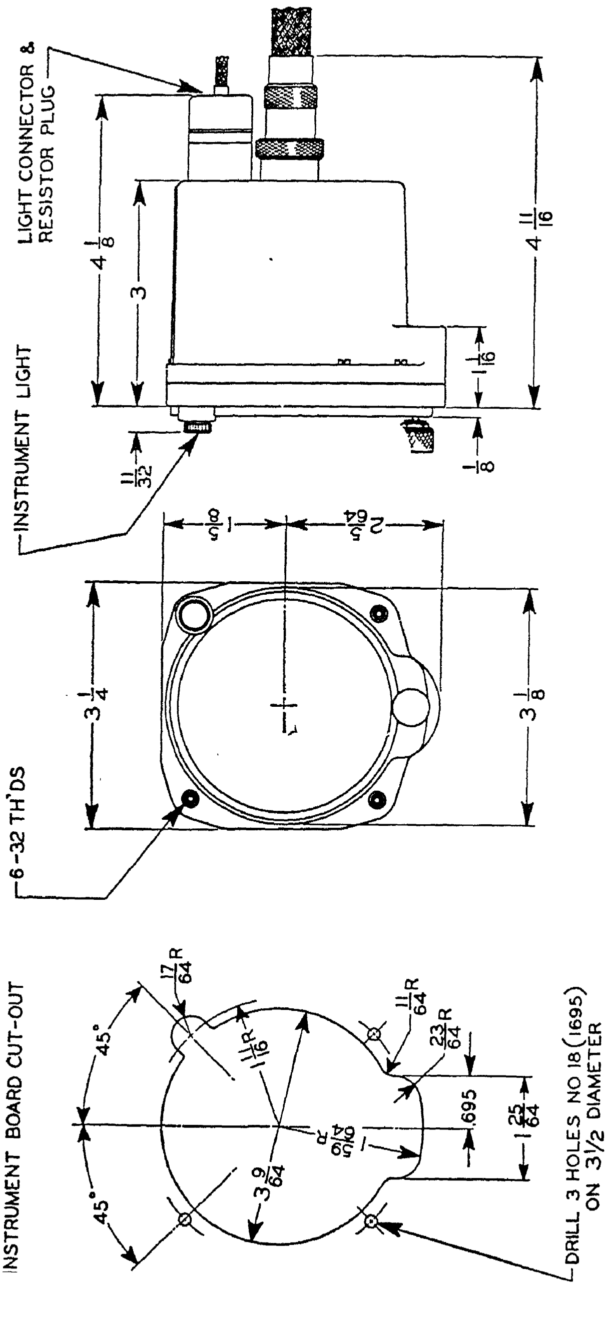


Figure 203. Installation Dimensions for Indicator Type 465 SD

CHAPTER 24

SPERRY GYRO HORIZON

In clear weather the pilot may use the natural horizon as his reference for level flight.

He has two organs of sensation which assist, his eyes and his "deep muscle sense" or "the feel of his pants." But in blind flight these organs are affected by the pull of gravity, centrifugal force, and longitudinal accelerations. Therefore, if he cannot see the natural horizon his sense of balance is inaccurate. Experiments have shown that in blind flight, and with the instrument panel covered, a pilot cannot definitely determine the true attitude of the airplane.

The gyro horizon affords an artificial horizon within the airplane and provides a reference on the instrument panel which simulates what might be seen if he had good visibility outside the airplane.

Operation

The gyro horizon derives its indication from a gyro spinning in a horizontal plane about a vertical axis Z. (See Figure 205.)

The mechanism of the instrument is mounted in the case, pivoted about the longitudinal (rolling) axis X. The gyro is contained in the housing (1) which is carried on pivots in the gimbal ring (4) so as to be free about the athwartships (pitching) axis Y. The horizon bar (2) is carried on an arm pivoted at the rear (5) of the gimbal ring and is controlled by the gyro through the guide pin (3). When the airplane noses up as in Figure 206, the plane of the gyro remains horizontal, causing the horizon bar to go down through its connection at the guide pin. Thus the miniature reference airplane in the instrument is above the bar, showing a nose-high condition. Reverse action takes place (Figure 207) in the case of a nose-down condition.

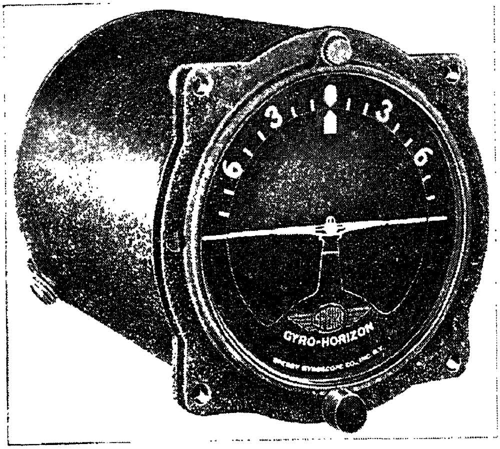


Figure 204. Gyro Horizon

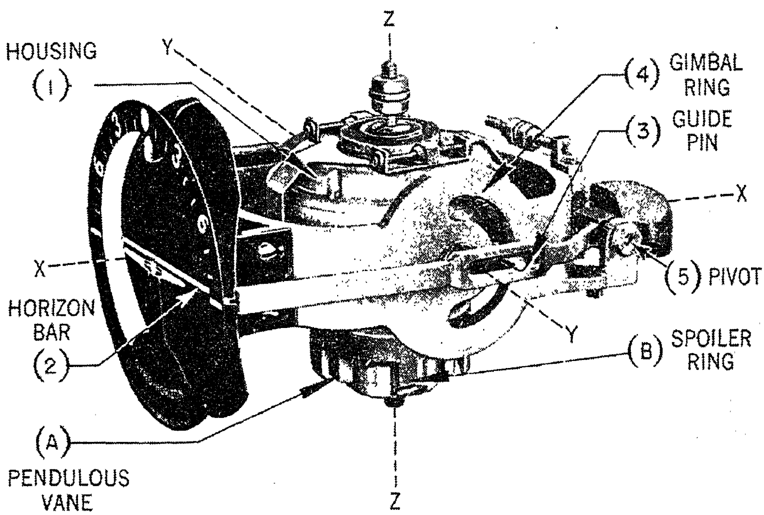


Figure 205. Principal Parts of the Gyro Horizon
(The Sperry Gyroscope Co.)

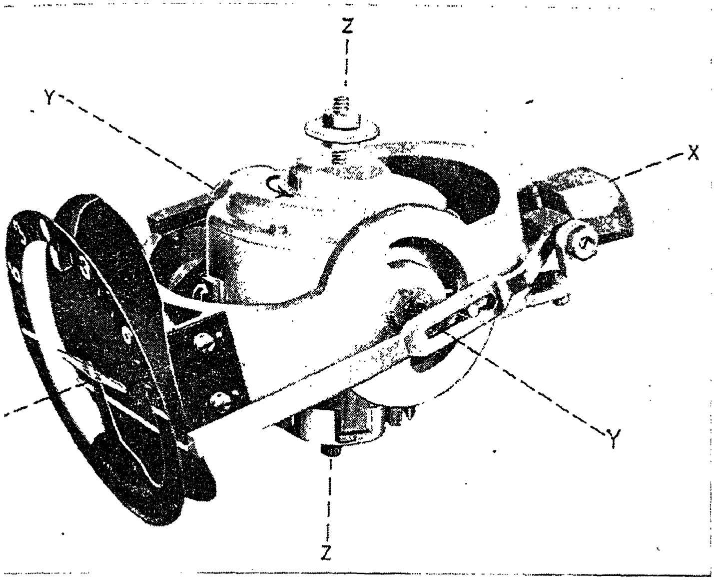


Figure 206. Gyro Horizon Mechanism in Climb

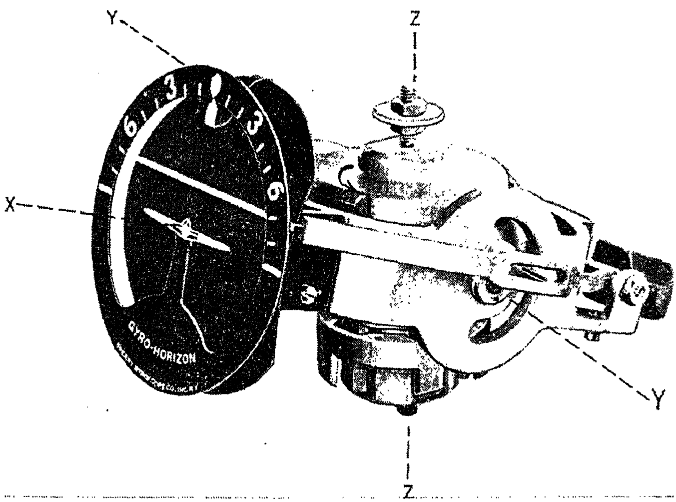


Figure 207. Gyro Horizon Mechanism in Glide
(The Sperry Gyroscope Co.)

When the airplane banks, only the instrument case and the miniature airplane are carried with it, while the mechanism of gyro wheel, gimbal, and horizon bar remains level (Figure 208).

Four pendulous free-swinging vanes (A) are suspended under the housing of the gyro. When the gyro housing is vertical, each of the vanes partially covers its respective air port (B).

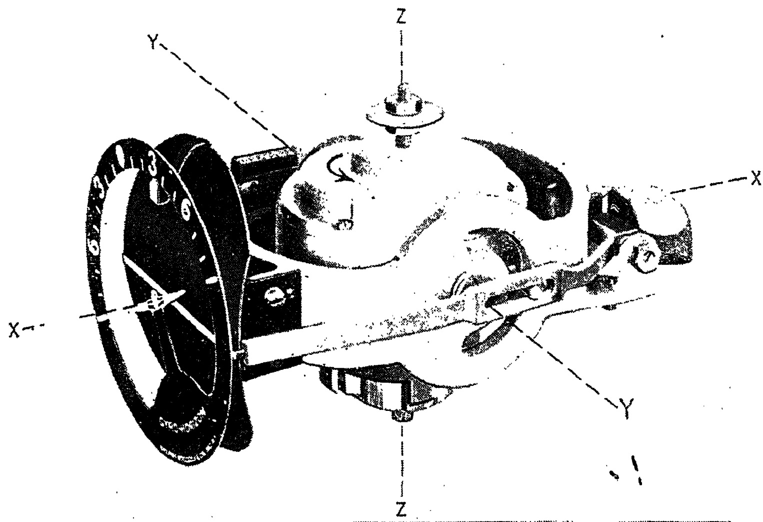


Figure 208. Gyro Horizon Mechanism in Bank
(The Sperry Gyroscope Co.)

These air ports exhaust the air which drives the gyro in the housing. In flight if the gyro attempts to assume a position other than vertical, the pull of gravity tends to hold the vanes in a vertical position and therefore one port will be closed by a vane and the opposite port will be open as shown in Figure 209.

The force of the exhaust air from the port will cause the gyro to move in the direction C until it assumes its normal vertical position. The rate at which the gyro precesses in response to the pendulous vanes is so slow that precessional forces created by the swinging of the vanes in rough air cancel one another before they have time to displace the gyro, and a

true horizontal is established. A turn, especially of 180°, would tend to displace the gyro axis slightly from the true vertical, causing an erroneous indication of the horizon bar for a short time after turn is completed. This is because the vanes, being pendulous, are affected by acceleration during the turn, with the result that the exhaust port on the side affected, instead of being opened partially, is opened completely, with consequent preces-

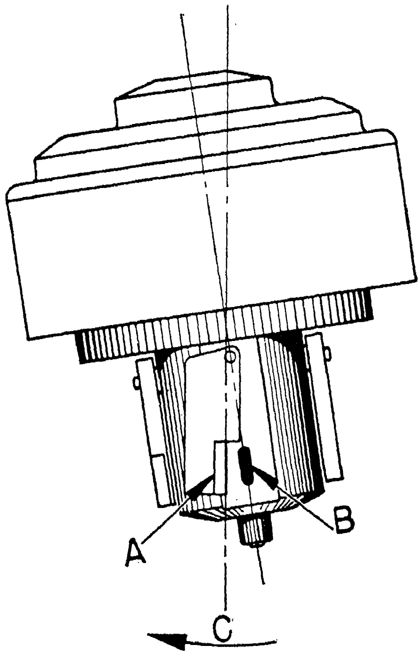


Figure 209. Erecting Action of the Pendulous Vanes of the Gyro Horizon
(The Sperry Gyroscope Co.)
Pendulum shown with spoiler ring removed.

sion of the gyro away from the vertical axis. In order to prevent the instrument from giving an erroneous indication, a precession retarding device or spoiler ring is used. This ring is shown at B in Figure 205; whenever one of the exhaust ports is completely uncovered by its pendulous vane, as it would be during a turn or during erection to the vertical, most of the air which is being emitted, instead of reacting on the gyro, is intercepted by the spoiler ring. The precession rate is therefore

reduced, and it follows that the effect on the gyro resulting from a turn is very small. As the error is almost imperceptible, the airplane can be leveled out safely by gyro-horizon indication when flying blind.

Flying with the Gyro Horizon

Flying with the gyro horizon is much like flying with a visible natural horizon. It may be thought of and used in either of two ways. Some like to consider it as a window through the instrument panel and through the fog and clouds, in which case the horizon bar is where the natural horizon would be. Others fly the miniature airplane with respect to the horizon bar (see Figure 210). The pictures in Figure 210 clearly indicate the position of the miniature airplane in respect to the horizon bar.

Straight, Level Flight. The gyro horizon is used as the basic reference for lateral and longitudinal control of the airplane. The horizon bar in the instrument remains parallel to the natural horizon while the miniature airplane is fixed to the case and remains parallel to the athwartships axis of the airplane. Lateral control is, therefore, accomplished by flying the airplane so as to keep the miniature airplane parallel to the horizon bar. For longitudinal control the horizon bar is connected to the gyro in such a manner as to cause the bar to take a position relative to the miniature airplane equivalent to the position of the aircraft to the natural horizon. In other words, the miniature airplane is above the horizon bar when the aircraft is nose high and below the bar when the airplane is nose down. Thus longitudinal control is similar to lateral control in that control is applied to keep the miniature airplane on the horizon bar in the same manner that the nose of the aircraft is held on the natural horizon.

Since the fore and aft attitude of an airplane varies for level flight according to altitude, power and load it will be necessary at times to fly slightly nose up or down according to the standard gyro horizon. The correct indication to use is quickly determined by observing the rate of climb indicator. The gyro

Figure 210. Gyro Horizon Indications

horizon is provided with an adjustable airplane which can be set to match the bar for a given flight condition.

Climbs and Glides. A climb or a glide of 70° may be made in precisely the same manner as if the natural horizon was used. Any climb or glide in excess of 70° will cause the gyro to strike the limit stops, thereby causing it to precess. The indication will be inaccurate until gyro can reassume its true vertical position.

Turns. When the directional gyro is used with the gyro horizon accurate turns can be made. The gyro horizon is subject to a slight error at the end of a turn, especially of 180°. This error does not become cumulative during continuous turning but instead begins to cancel out after 180° of turn.

Take-Offs. Take-offs which require the use of instruments should only be made in airplanes equipped with a vacuum pump for operating the gyro instruments. The instruments should run at not less than 3″ of vacuum for at least 5 minutes before take-off to make sure that the gyro is up to full speed. The miniature airplane is kept in the same position relative to the horizon bar as it occupies during a clear weather take-off.

Landings. The fore and aft and lateral attitude of the airplane, in an approach to the airport, is indicated by the position of the miniature airplane in respect to the horizon bar.

Testing the Gyro Horizon

Place the instrument on a testing block in a level position, and connect it to a vacuum pump and a manometer by means of rubber tubing. (The outlet not used must be kept plugged.) Adjust the miniature airplane by means of the knob at the bottom of the bezel until the wing is exactly in line with the indices at either side of the bezel.

Build up a vacuum slowly and when the manometer indicates that the vacuum has reached 3½″ (89 mm.) Hg, note the time required for the horizon bar to reach the correct settling position as shown in Figure 211. The horizon bar should be exactly in line with the indices at either side of the bezel.

Settling Position of the Gyro Horizon

The time required will be proportional to the amount the horizon bar is displaced when the test is started. For instance, if the pointer at the top of the dial shows a 30° tilt of the gyro, at least six minutes will be required.

Continue to run the instrument at 3½″ Hg, and at the expiration of ten minutes the horizon bar should be centered within the tolerances designated in Figure 211.

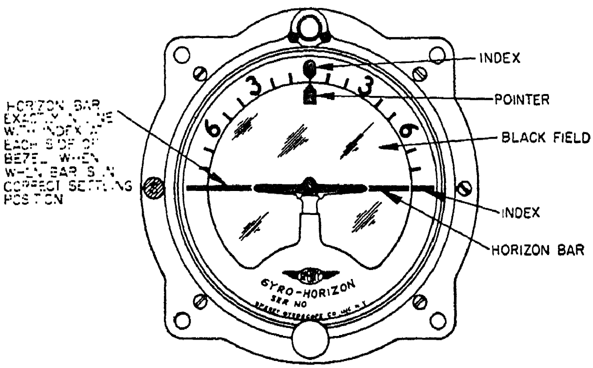


Figure 211. Settling Position of the Gyro Horizon
(The Sperry Gyroscope Co.)

If the bar should fail to settle as described, shut off the vacuum pump and allow the gyro to come to a full stop. See that the instrument is level in all directions and repeat the test.

Note: Sometimes the bar will vibrate considerably when the instrument is first started. This vibration will stop as the gyro reaches normal speed.

If the horizon bar settles within the limits specified, the instrument is ready for installation.

Installation

The gyro horizon and the directional gyro are usually mounted close together and operate from the same source of vacuum. General installation data for both are listed together here other than directional gyro installation dimensions.

Installation Layout. A venturi tube (Figure 212) is sometimes used for operating the gyro horizon and directional gyro but it is recommended that an engine-driven vacuum pump be used whenever possible.

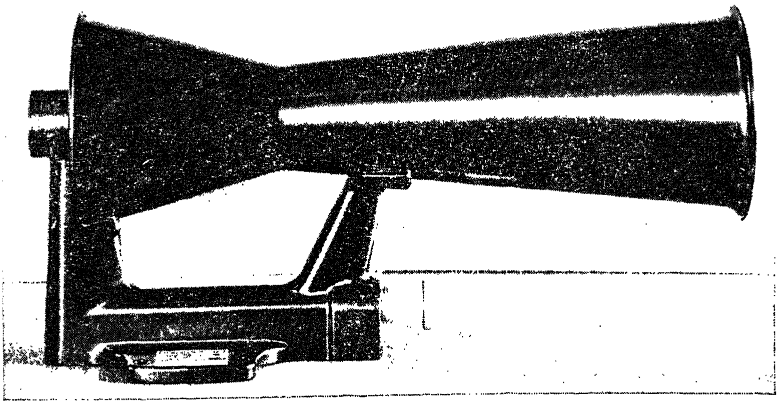


Figure 212. The Venturi Tube

Used in connection with a vacuum relief valve (Figure 213) the pump or venturi tube insures that the instruments will

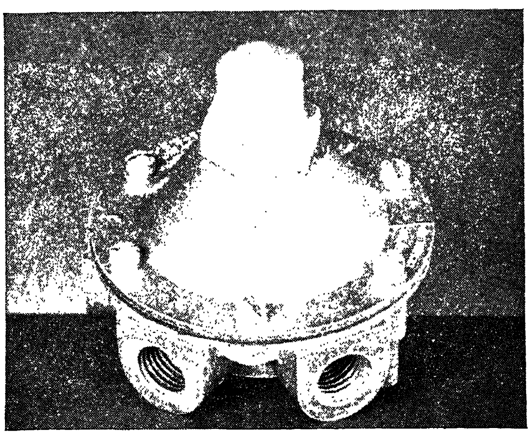


Figure 213. The Vacuum Relief Valve

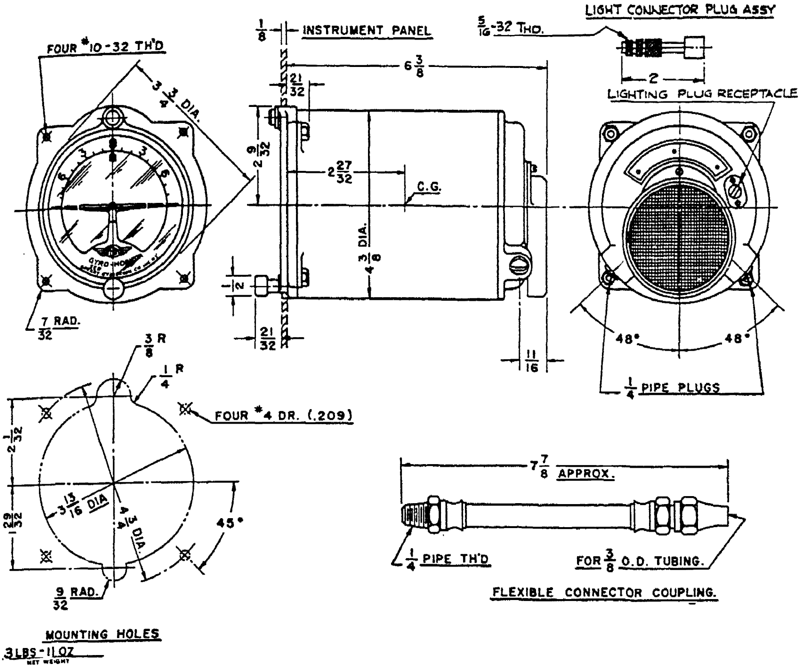


Figure 214. Installation of Standard Gyro Horizon

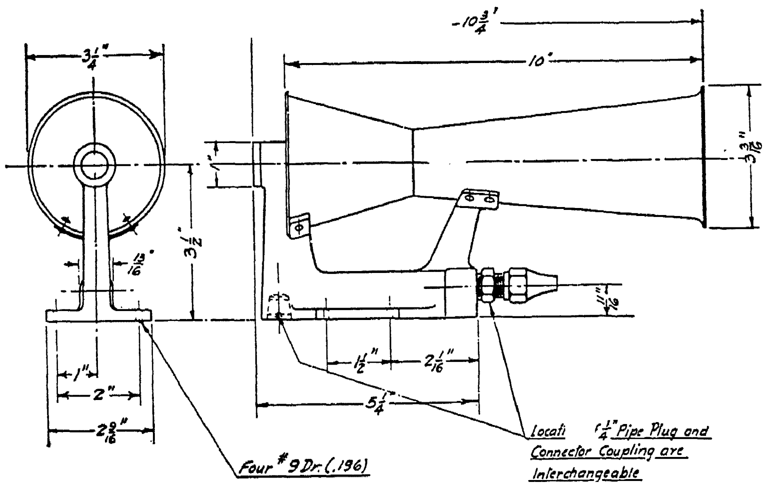


Figure 215. Installation of Venturi Tube

(The Sperry Gyroscope Co.)

operate under proper vacuum at all times except when the engine is turning less than 1,000 r.p.m.

The use of a vacuum gauge which shows whether or not the instruments are operating at proper vacuum is also recommended. It is absolutely necessary that the instruments be mounted on a properly shock-absorbed instrument panel. Unless instruments are properly protected from vibration in excess of 0.004″ amplitude satisfactory performance cannot be expected.

Installing the Instruments. The gyro horizon and the directional gyro should be mounted closely together. They should be so mounted that when in flying position, the dials will be vertically true. The panel should be perfectly flat and the mounting lugs evenly touching the panel. The mounting screws should be tightened evenly and in a rotative manner.

Installation of the Venturi. With 12 feet of ⅜″ O. D. tubing the venturi will produce 3½″ vacuum at 125 miles per hour or 4½″ of vacuum at 175 miles per hour. For a speed greater than 175 miles per hour a vacuum relief valve should be used to prevent too high a vacuum. The venturi should be located in the slipstream to assist the gyro in starting while the plane is warming up on the ground.

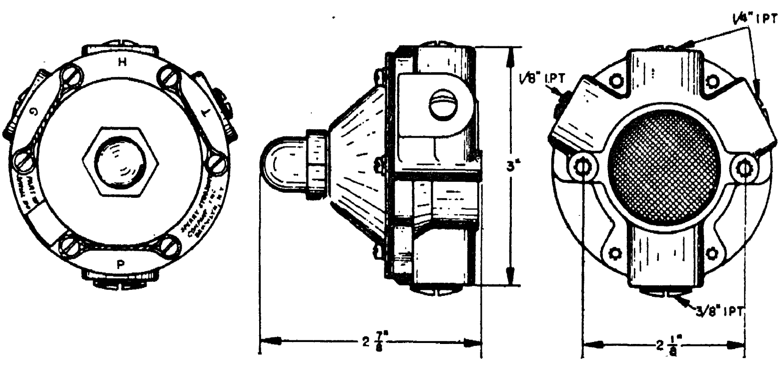


Figure 216. Installation of Vacuum Relief Valve

Installation of the Vacuum Relief Valve. It should be installed as near as possible to the instruments. The intake screen should be facing downward.

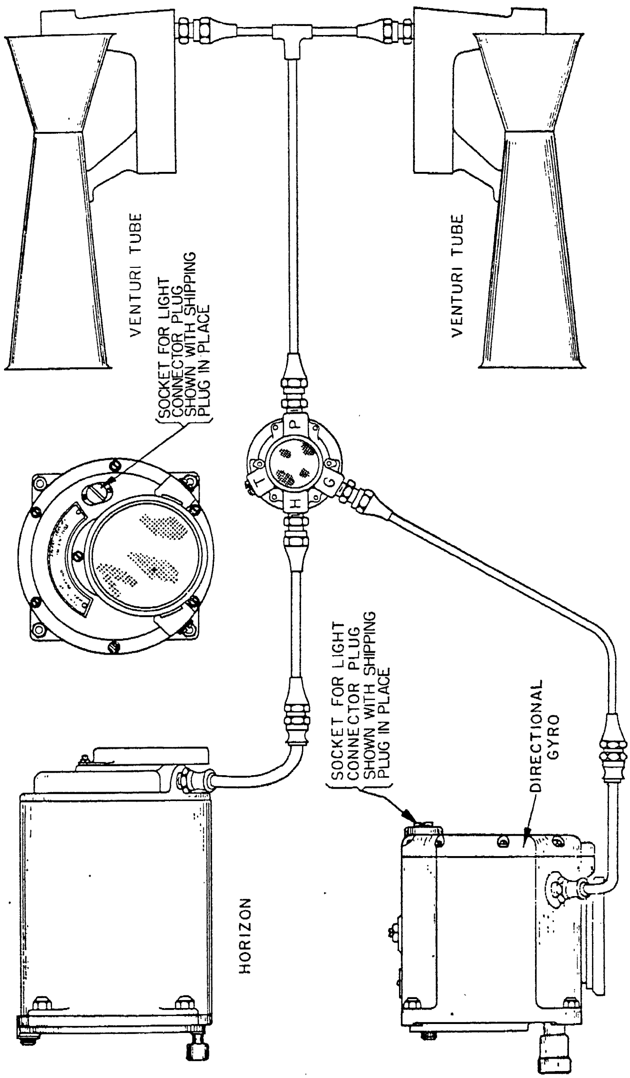


Figure 217. Connecting Diagram of Instruments

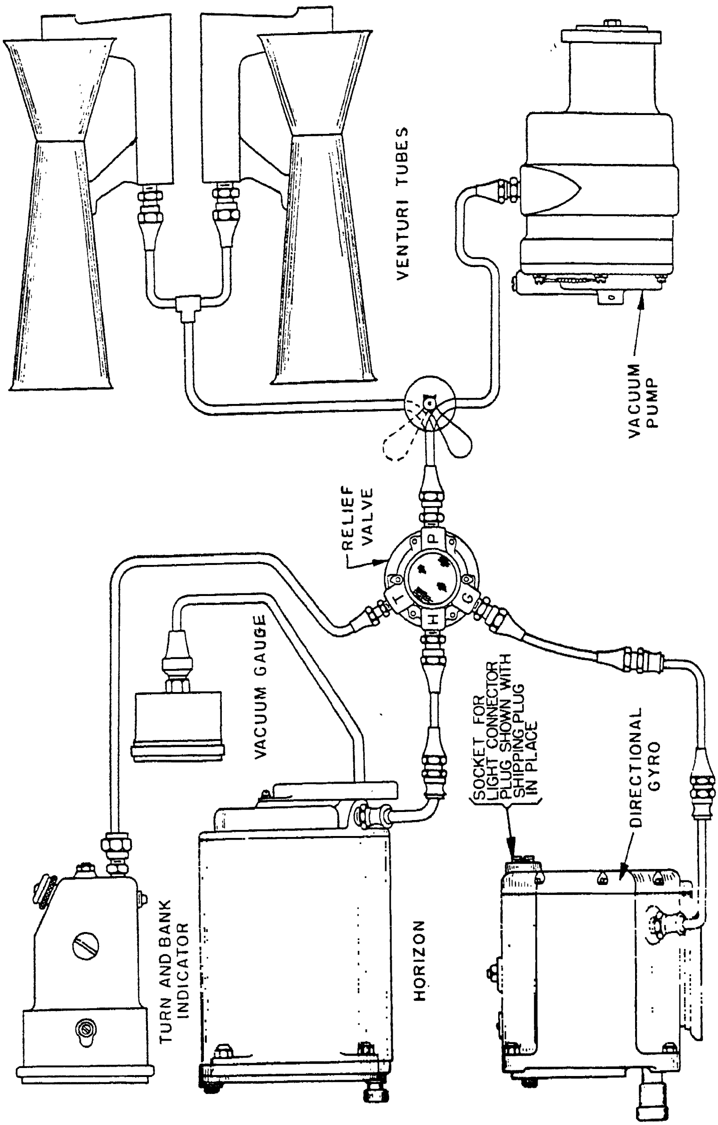


Figure 218. Another Connecting Diagram of Instruments

Maintenance

Listed below are troubles which might occur and their probable causes:

Troubles	Probable Causes
Horizon bar fails to respond.	Leaks in tubing, complete stoppage in tubing, failure of the vacuum pump, air filter disc dirty or leaks in instrument case around glass or fittings.
Horizon bar fails to settle.	Air filter disc dirty, low vacuum or excessive vibration of the instrument panel.
Horizon bar oscillates.	Vacuum may be too high or excessive vibration of the instrument panel.

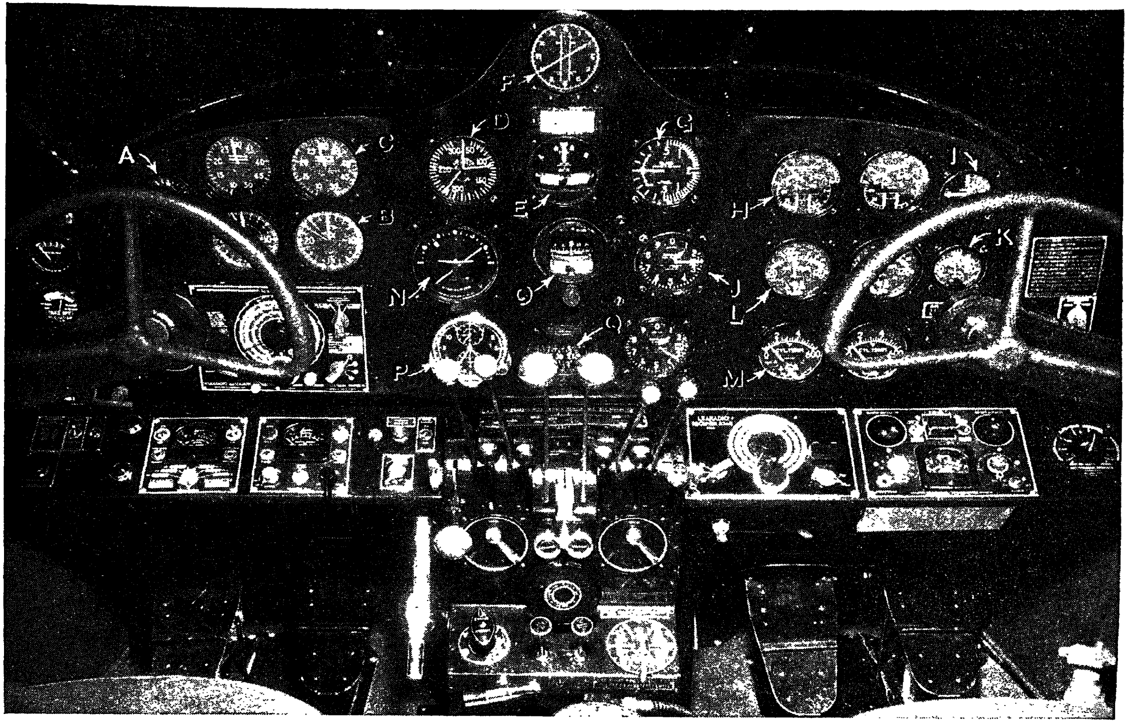


Figure 219. Beechcraft Model 18 Twin-Engined Instrument Panel

A—Suction Gauge
B—Tachometer
C—Manifold Pressure
D—Air Speed
E—Turn and Bank
F—Direction Indicator
G—Rate of Climb
H—Engine Gauge Unit
I—De-icer Gauge
J—Altimeter
K—Carburetor Temperature
L—Free Air Temperature
M—Cylinder Temperature
N—Artificial Horizon
O—Directional Gyro
P—Clock

CHAPTER 25

SPERRY DIRECTIONAL GYRO

The directional gyro, although not considered one of the primary flight group, is always used in conjunction with these instruments. It provides a fixed reference within the airplane and gives a reliable direction indication.

Operation

The directional gyro is essentially a spinning gyro pivoted in a horizontal plane with an azimuth card graduated in 1° increments, and a setting device for turning the azimuth card to any desired heading.

In Figure 222 the gyro (1) spins around the horizontal axis (H) at about 10,000 r.p.m. and is mounted universally. It is pivot mounted in the gimbal ring (2) which is free to turn in the vertical ring (3) about the axis (G). The vertical ring is free to turn in a vertical plane about the axis (V). The azimuth card is attached, by screws, to the vertical ring and is visible to the pilot as shown in Figures 220 and 221. Because of the precision construction and nearly frictionless mounting, the gyro will observe the fundamental principle of the gyro rigidity. In other words, it will remain fixed, as will the gimbal ring, vertical ring, and the attached card. The airplane in making turns will move around them. The lubber line shown bisecting the zero in Figure 220 is the reference line from which the readings of the card are taken. The caging knob (5) when pushed in meshes with the synchronizer pinion (6) and with the synchronizer gear (7). By turning the caging knob the card may be set to correspond to the reading of the magnetic compass.

When the caging knob is pushed in, it engages the synchronizer lever plunger and raises the lever pins (8) which rest in the groove (9). The synchronizer ring is raised which pushes

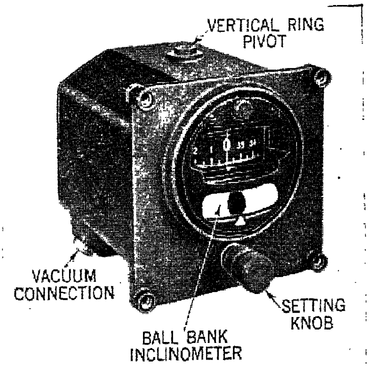


Figure 220. Directional Gyro with Ball Bank Indicator

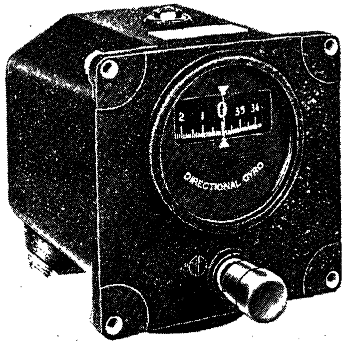


Figure 221. Standard Directional Gyro

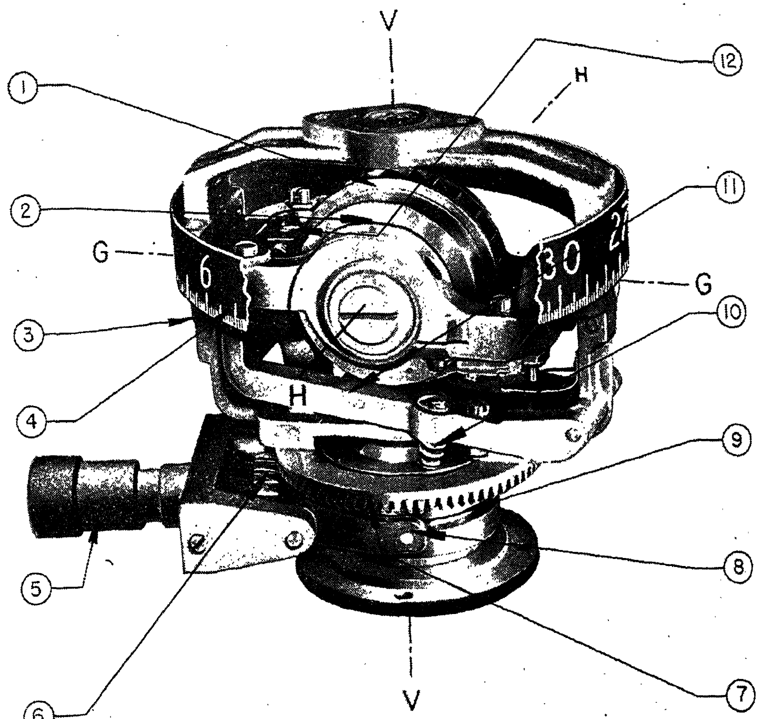


Figure 222. Principal Parts of the Directional Gyro
(The Sperry Gyroscope Co.)

the spring plungers (10) upward and raises the caging arm (11) causing it to make contact with the gimbal ring. The gyro is held horizontal while the card is turned to the correct heading. As the caging knob is pulled out, the caging mechanism is released and the gyro is horizontal and free. The air which flows through the air jets of the nozzle (12) spins the rotor and also tends to keep it upright. The two air jets (Figure 223) are parallel and the air flowing through them strikes the

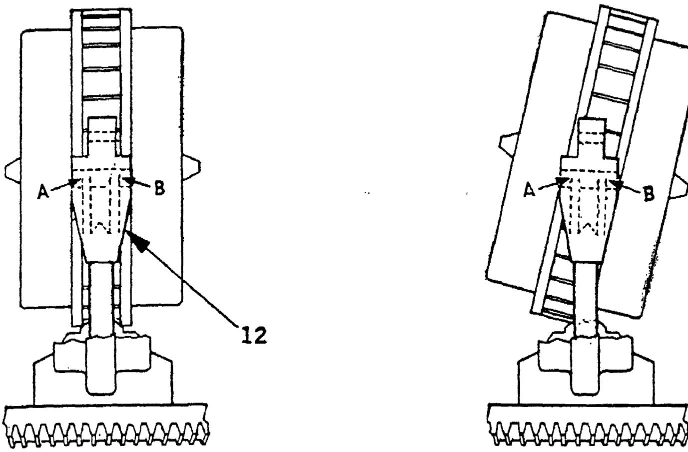


Figure 223. Erecting Action of the Air Nozzle
(The Sperry Gyroscope Co.)

gyro buckets equidistant from the center of the rim of the gyro. If the gyro attempts to move from its true position, the air from jet (A) will strike the rim while the air from the opposite jet (B) will strike the side of the gyro buckets. This will cause the rotor to assume its correct upright position.

Flying with the Directional Gyro

In some respects the directional gyro when properly set may be likened to the magnetic compass, since both indicate direction and are mainly controlled by the action of the rudder. The main difference is that the directional gyro is more reliable in its indications, particularly in rough, bumpy weather. The com-

pass card is free revolving in liquid with no corrective force and therefore will oscillate during "yawing" of the airplane.

In blind flight it is best to rely on the directional gyro for direction indication until such time as the compass becomes steady. The directional gyro may "creep" as much as 3° in 15 minutes; therefore, it should be checked at frequent intervals with the magnetic compass and reset if necessary. The fact that it does not lag or oscillate makes it invaluable as a means of making precise turns. Some directional gyros incorporate a ball bank inclinometer, Figure 220, which may be used to prevent slipping or skidding.

Take-offs. Take-offs may be made with the directional gyro by setting and uncaging the gyro and holding the airplane on a fixed heading. The airplane should be equipped with an engine-driven vacuum pump and the instrument operating at not less than 3″ of vacuum for at least 5 minutes, to be sure that the gyro is turning at full speed.

Turns. The directional gyro may be used with the gyro horizon for climbs, glides, and bank up to 55° displacement. The pointer on the dial of the gyro horizon will indicate the bank in degrees, the miniature airplane indicates the position of the airplane in respect to the true horizon, the ball in the inclinometer (see Figure 220) will indicate the correctness of the bank and the card of the directional gyro will indicate the turn in degrees. If a climb, glide or bank of more than 55° is attempted, the directional gyro should be caged to prevent injury to the instrument.

Landings. The directional gyro will assure the pilot of a straight approach for landing by holding the airplane on the desired heading.

Shop Testing of the Directional Gyro

Prior to installation and at any time after installation, when it appears that the instrument is functioning inaccurately, it should be tested as follows:

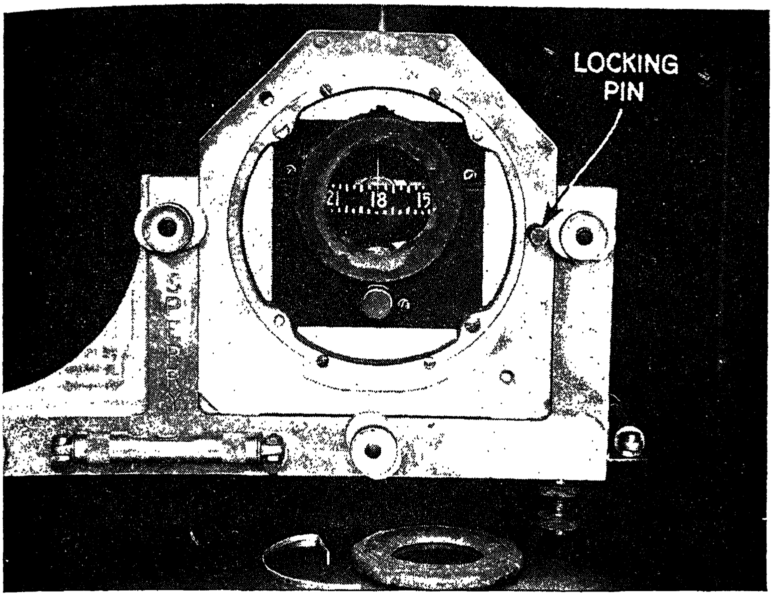


Figure 224. *Above:* The Instrument Ready for Calibrating. *Below:* Temporary Lubber Line and Glass Prepared with Vulcatex for Placing on Front of Instrument

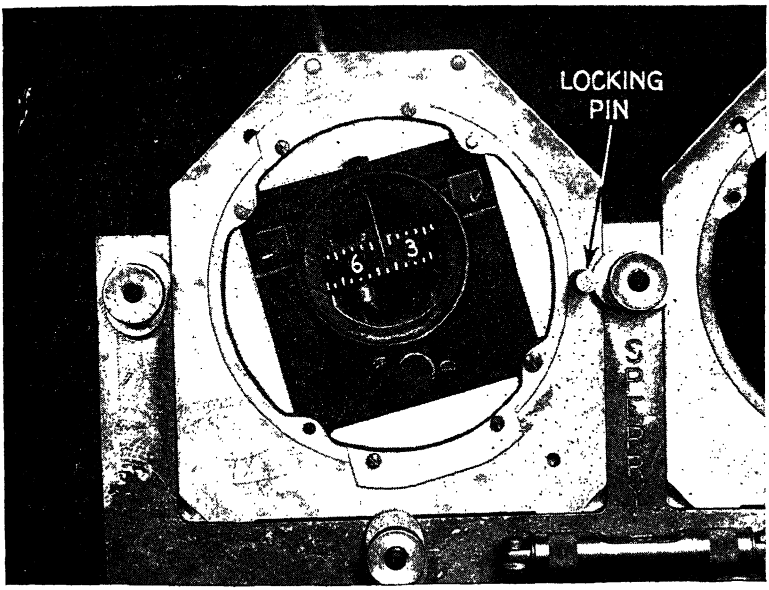


Figure 225. The Instrument in the Calibrating Fixture, Tilted 15°
(The Sperry Gyroscope Co.)

Remove one of the plugs at the rear of the case and by using a union, connect the instrument to a source of vacuum.

A mercury manometer should be teed parallel into the vacuum line near the instrument.

Create a vacuum (by noting the mercury manometer) of 3½" of Hg and allow the instrument gyro to run 10 minutes.

Push the caging knob *in* and set the card at zero heading, then pull the knob *out*. Allow the instrument to run for 20 minutes.

Run the instrument on the 9, 18, and 27 headings in a like manner. Note the drift of the card each 5 minutes during a run. The drift should not exceed 3° in either direction for any 15-minute period for any of the headings. A maximum drift of 5° is allowable on any one heading providing the total drift of the four headings does not exceed 12°.

The following examples will elucidate the procedure:

	Heading	Drift in Degrees
(1)	0	−2
	90	5
	180	2
	270	−3
		12 Acceptable
(2)	0	2
	90	5
	180	−3
	270	−3
		13 Rejectable (Excessive total)
(3)	0	4
	90	5
	180	0
	270	−3
		12 Rejectable (Excessive drift on more than one heading)

Installation

Figures 226 and 227 show the installation dimensions for both the standard and ball bank type. Both the directional gyro

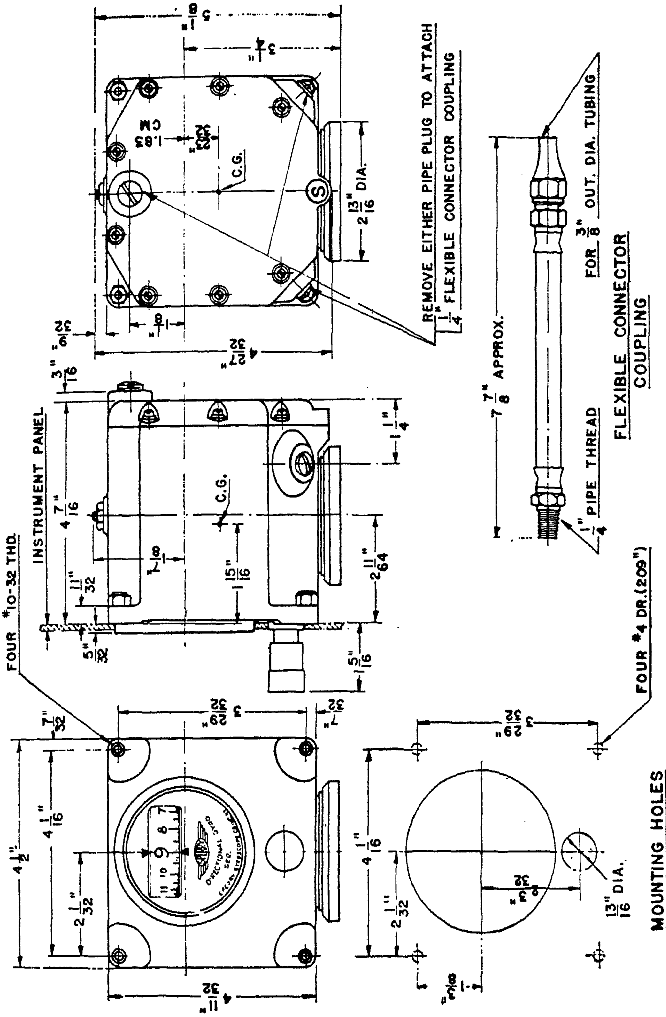
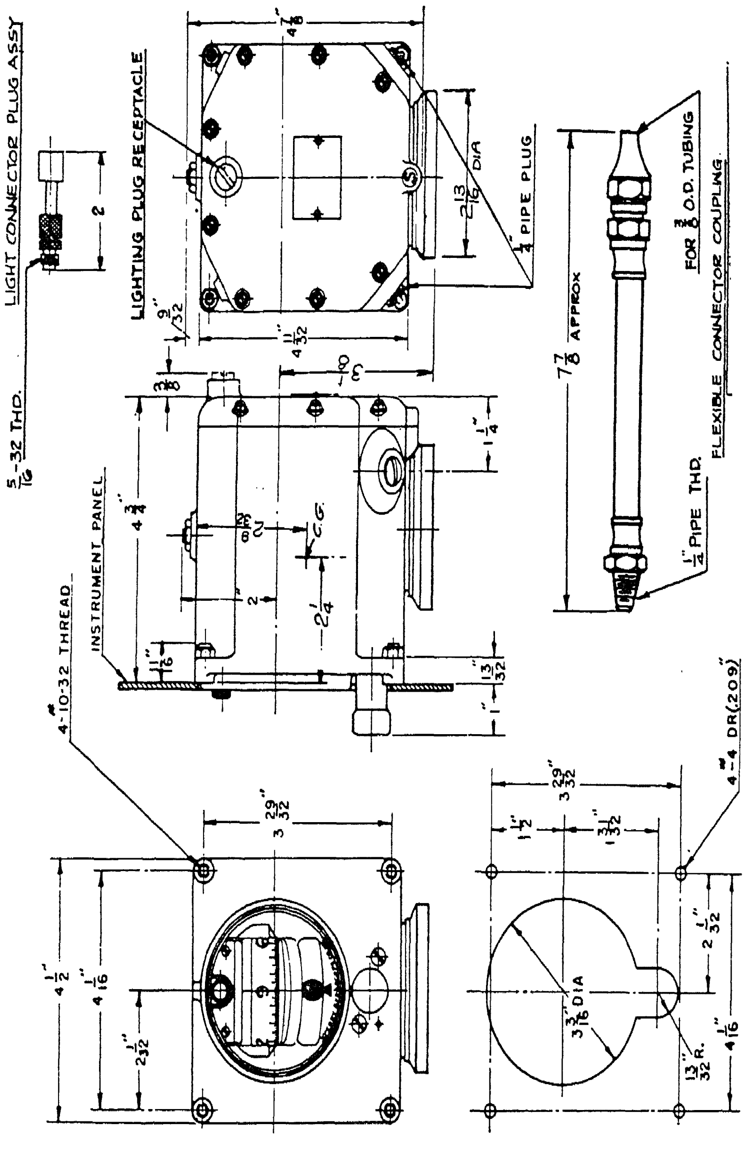


Figure 226. Outline Drawing of Standard Directional Gyro
(The Sperry Gyroscope Co.)



Drawing of Direct
(The Sperry Gyr

and gyro horizon are mounted as close together as possible and operate from the same source of vacuum. For full details see "Installation" under the gyro horizon.

Installation Tests

Leveling of the Instrument. After installation it is well to see that the instrument is level. On the type with ball bank incorporated, this may be done by observing the ball in respect to the triangular reference marker, Figure 220. On the standard type, place a bubble level on a parallel line with the card. If the instrument is not quite level laterally, the mounting holes may be slightly elongated, providing specification tolerances are not exceeded.

Vacuum Check. If the airplane is provided with an engine-driven vacuum pump, run the engine at cruising speed (on the

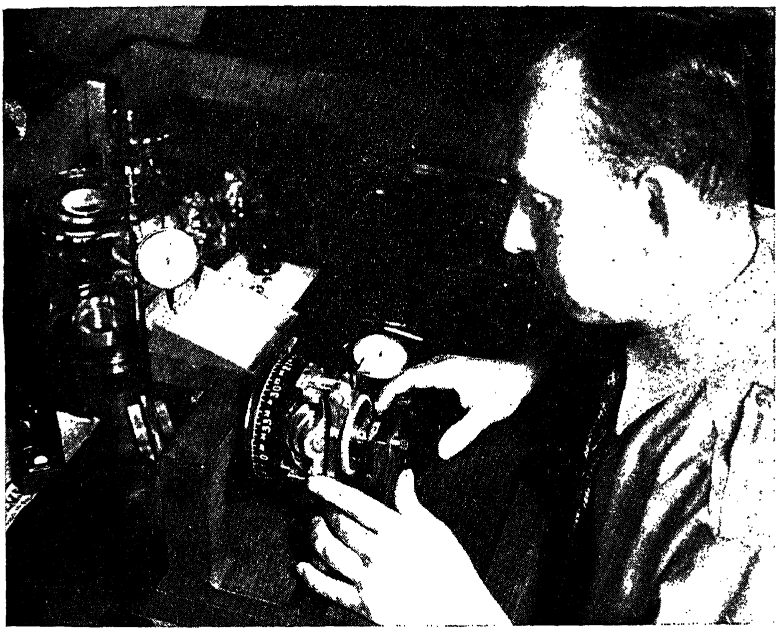


Figure 228. Instrument Overhaul
(American Airlines, Inc.)
Perfect balance of the Sperry directional gyro mechanism is necessary for the correct performance of the instrument. Photo shows an American Airlines instrument technician making the final tests before the instrument is placed in its case.

ground) and adjust the vacuum relief valve so that the instrument will hold 3½" to 4" of Hg vacuum. If the airplane is equipped with a venturi tube the airplane is flown at cruising speed.

Maintenance

The following will assist in determining vacuum errors:

Vacuum under 3½" at cruising speed (too low).	(a) Venturi in improper location. (b) Connecting tubing too small or too long. (c) Leaks in connections. (d) Tubing restricted or kinked.
Vacuum over 4½" at cruising speed (too high).	(a) Provide a reducing or relief valve. Adjust to 4" of Hg vacuum. (b) Move venturi to new location.
Dial drifts too much in either direction or spins continuously in one direction.	(a) Incorrect vacuum. Adjust properly. (b) Dirty air filter preventing correct air flow. Replace. (c) Excessive vibration. Should be no more than 0.004" vibration amplitude. Check with a vibrometer.

CHAPTER 26

THE SPERRY AIRCRAFT GYROPILOT, MODEL A-3 [1]

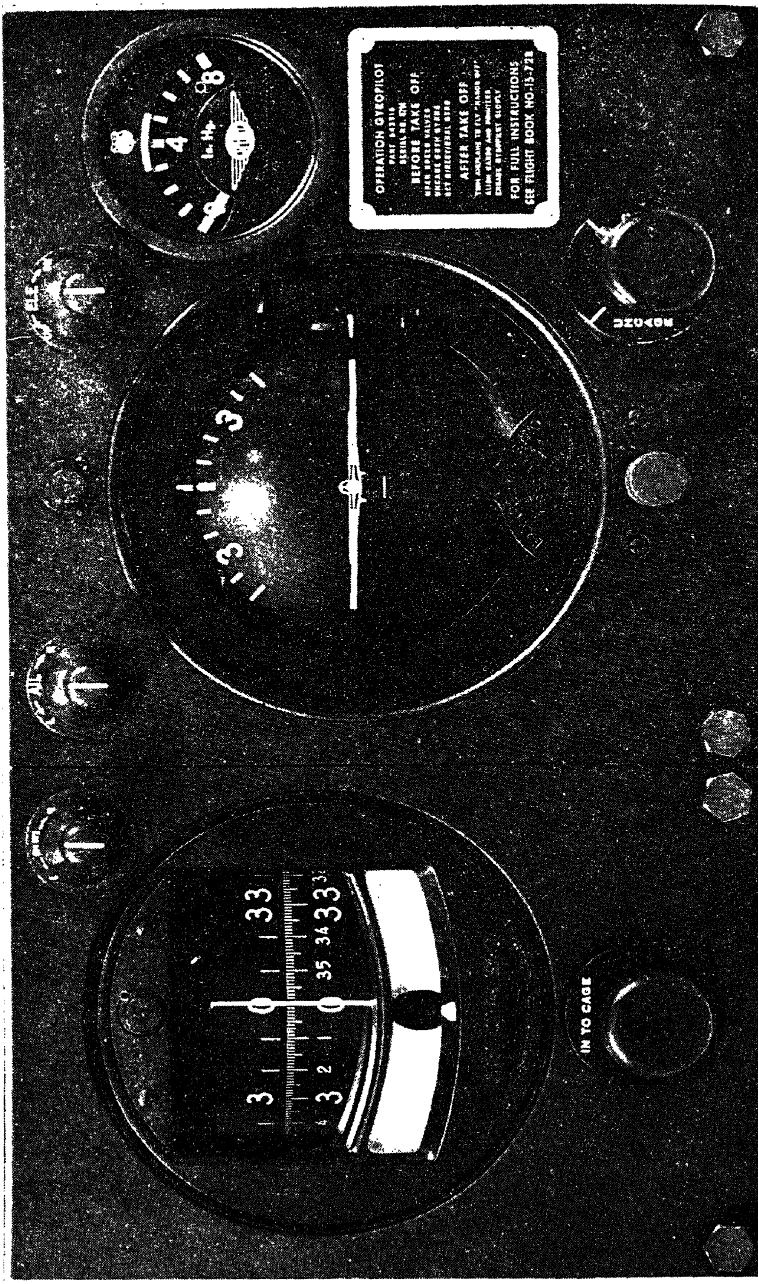
The Sperry Gyropilot has taken its place as an important factor in present day airplane operation. It is now being manufactured in quantity for transport, military and private airplanes. Its value is based upon its recognized ability to relieve the human pilot of the physical effort of flying and to hold the airplane on a steadier, truer course. The gyropilot contributes to the safety, comfort and efficiency of all types of airplane operations.

The gyropilot provides *complete* automatic control for lateral, longitudinal and directional motions of the airplane. It is compact and light in weight, contained as an integral part of the instrument board, where it provides the human pilot with a continuous picture of the directional, longitudinal and lateral attitude and angular movements of the airplane whether flying by automatic or by manual control.

The gyropilot is designed and built to give dependable service over a period of many years. As is the case with any other fine mechanism, the best results are dependent upon understanding, intelligent use, and proper care of the equipment. These instructions contain information on each of these several phases of gyropilot use.

It is extremely important that persons planning or making a gyropilot installation be thoroughly acquainted with the manner in which the gyropilot operates. This chapter contains the operating principles, a description of the equipment and instructions in use, servicing, and installation of the gyropilot in the airplane.

[1] Descriptive material and photos in this chapter have been made available to the author by the Sperry Gyroscope Co.


OPERATION GYROPILOT
BEFORE TAKE OFF
AFTER TAKE OFF
FOR FULL INSTRUCTIONS
IN TO CAGE

General Description

The gyropilot equipment consists essentially of a directional gyro control unit, a bank and climb gyro control unit, a mounting unit, and a servo unit together with the necessary accessories for the proper functioning of the equipment as a whole. The principle of operation is explained as follows:

A GYROSCOPE is a spinning wheel, universally mounted. Such a wheel exhibits a characteristic called "rigidity"; that is, it tends to remain in whatever position it is set. This property of "rigidity" is the basic principle in the operation of the gyropilot.

Two gyroscopes are used in the gyropilot. One of these is the directional unit, which supplies the reference for directional control (rudder). The other is the bank and climb unit, which supplies the reference for both lateral and longitudinal control (ailerons and elevator).

These two gyroscopes are identically the same as the ones which actuate the directional gyro and the gyro horizon. In the gyropilot, however, their accurate indications of flight attitude are utilized through a simple pneumatic-hydraulic system to obtain corrective movements of the aircraft's controls.

To illustrate the action of the gyropilot, only the aileron control of the bank and climb control unit will be used. The rudder and elevator controls are operated in a similar manner.

The bank and climb gyro spins with its axle vertical. It is erected by the action of pendulous vanes in exactly the same way as the gyro horizon. With the aircraft flying level, as shown at the top in Figure 230, the horizon bar on the dial of the gyropilot is level and the miniature airplane is parallel to it. The gyro remains fixed as the airplane banks, and the degree of movement is indicated on the dial of the gyropilot as shown at the top in Figure 231.

The gyro is supported in a gimbal ring which has a disc with knife edges attached to it. These parts comprise the sensitive element.

The air pick-offs A-A′ are enclosed in a box together with the gyro element. Air is drawn into the bottom of the box by

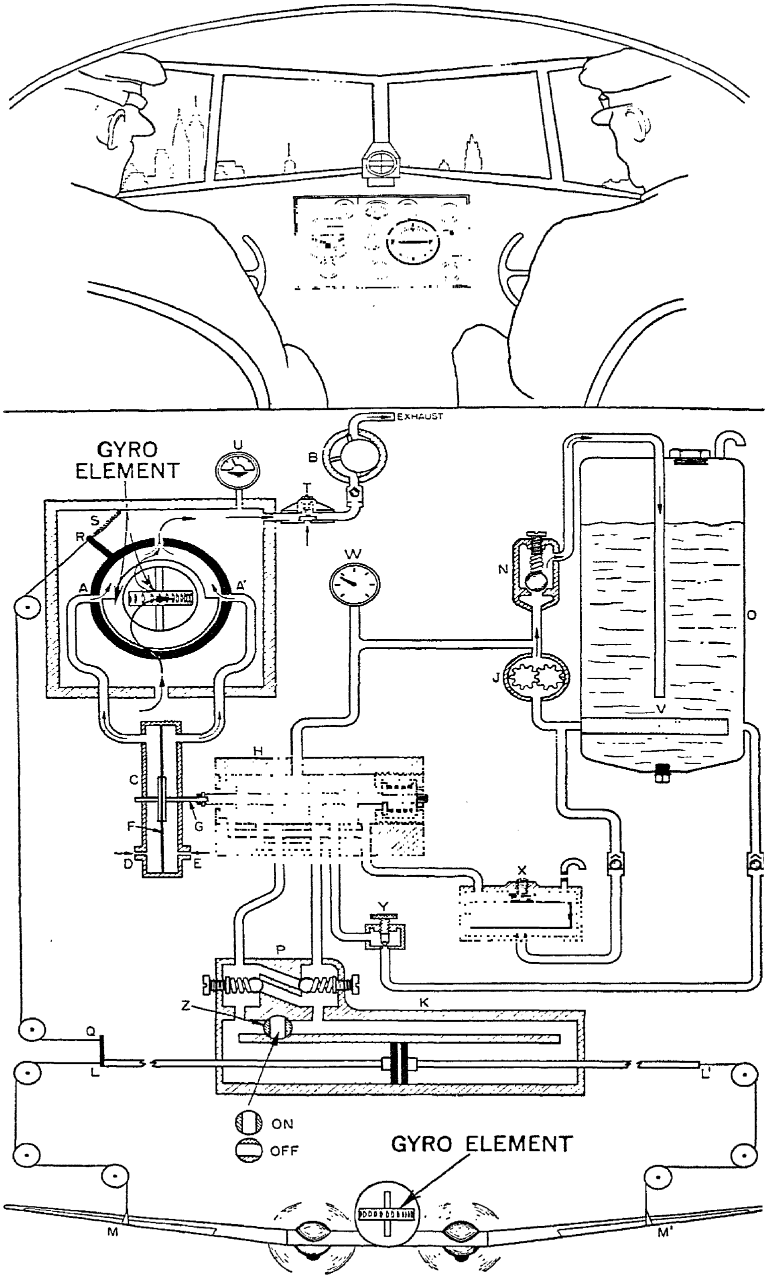


Figure 230. Schematic Diagram, Airplane Level

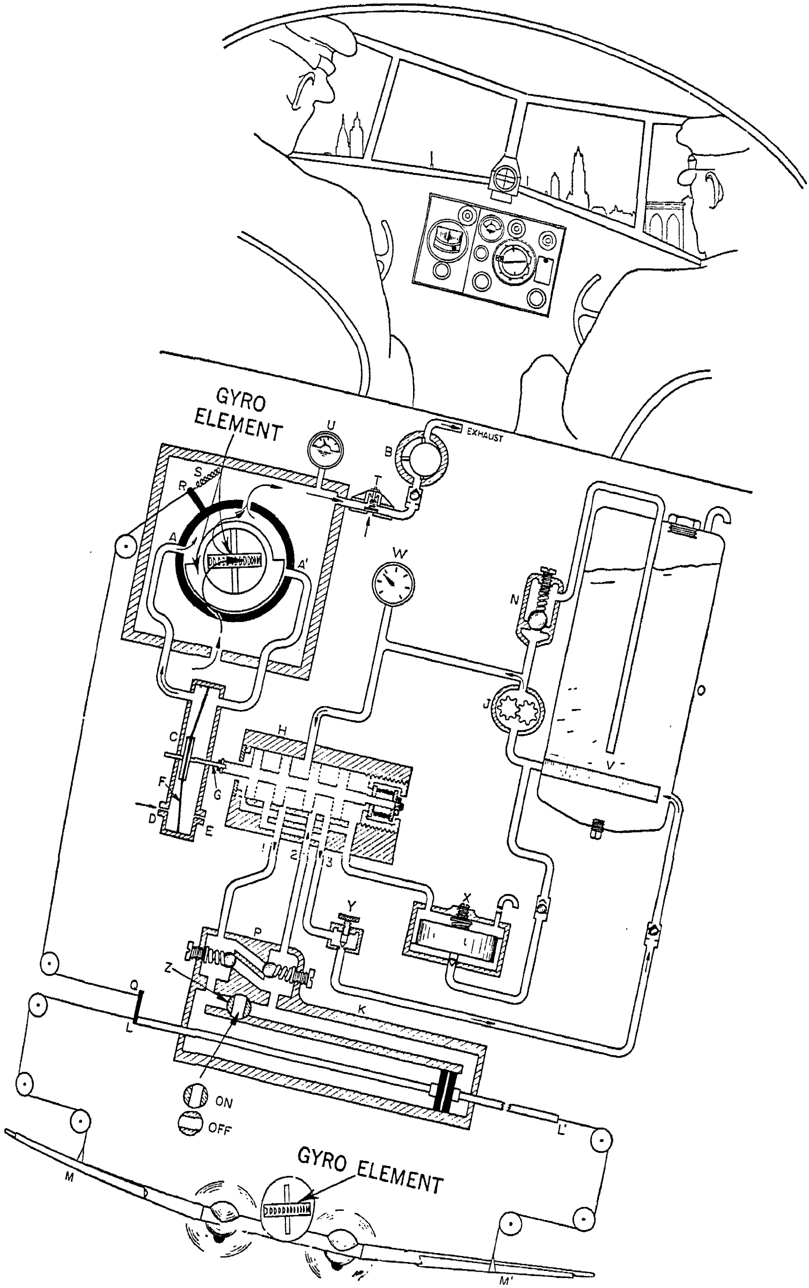


Figure 231. Schematic Diagram, Right Wing Down

the suction pump B, and directed to the gyro to spin it. Air is also drawn in from the air relay C through ports A-A′ and exhausted at the top.

The air relay C has two inlet ports D and E, on either side of the diaphragm F. The diaphragm is connected by the piston rod to G to the balanced oil valve H, in which a constant pressure is maintained by the oil pump J.

Movement of the core of the balanced oil valve to left or right permits oil to flow to the servo unit K where it moves the piston rod L-L′ one way or the other. The piston rod is connected to the control cables which operate the ailerons M-M′.

In Figure 230 the aircraft is assumed to be level laterally, and the gyropilot system is therefore neutral. The gyro is upright and the knife-edges of the disc intercept an equal amount of the air which is being drawn in from the air relay at D and E. Therefore, an equal suction is maintained at both sides of the diaphragm F, the oil valve piston is centralized, and no oil can flow to the servo cylinder. The pressure regulator N relieves the oil pressure at the balanced oil valve and permits the oil to flow back to the sump.

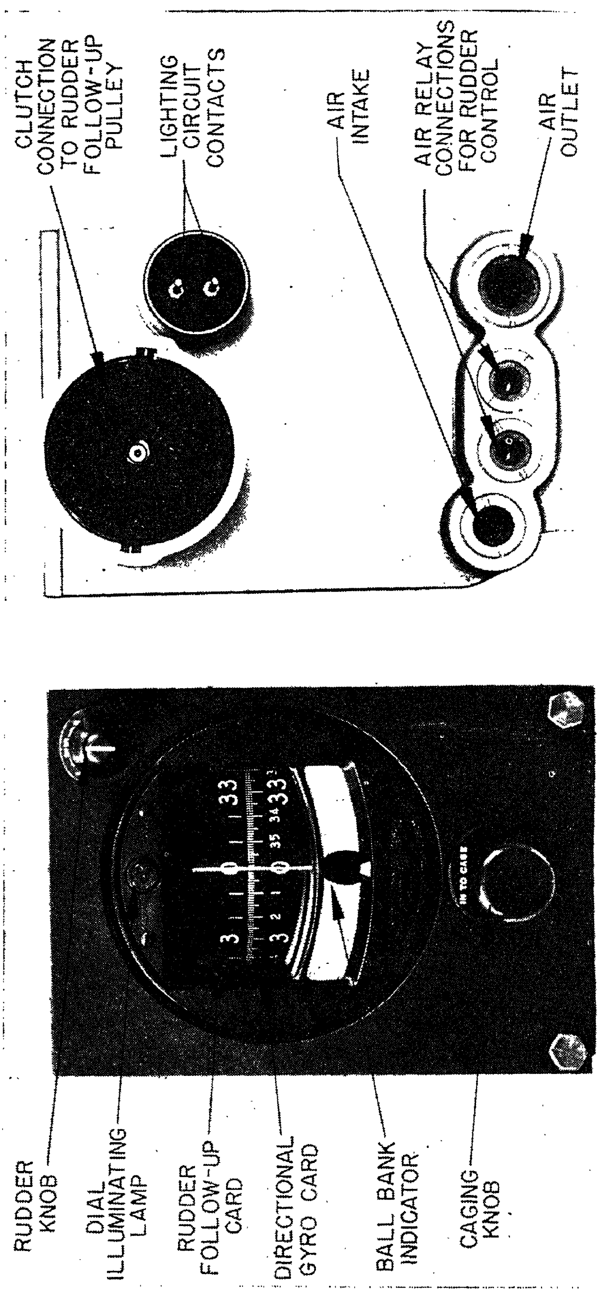
In Figure 231 the aircraft is assumed to have been displaced laterally (to an exaggerated degree) so that the right wing is lower than the left. The gyro (labeled) maintains its vertical axis, and port A′ of the air pick-off system is closed. Port A is opened, and therefore, the suction on the left-hand side of the diaphragm F is increased, and the diaphragm moves to the left. The corresponding movement of the balanced oil valve permits oil to flow through pipe 1 to the servo unit, where it passes around the overpower valve P and enters the servo unit cylinder, moving the piston to the right and applying the necessary aileron control to restore the aircraft laterally to level flight. The oil from the other side of the piston returns to the balanced oil valve through pipe 2 and flows back to the sump through pipe 3.

An important part of the system, the follow-up, is also shown diagrammatically in Figures 230 and 231. The follow-up provides a means whereby the applied control is removed as the

airplane is returning to its normal attitude, so that the control surface will be back in its neutral or centered position when the disturbance has been fully corrected. The air pick-offs A-A′ are not fixed rigidly to the gyro box, but instead can be moved in relation to the gyro element by means of the follow-up mechanism. A cable is connected to the servo piston rod at Q and attached to the lever R on the follow-up assembly. Follow-up movement is not shown in the diagram as it would alter the position of the air pick-offs, but the sequence of operation is as follows:

When the servo piston L-L′ moves to the right, the follow-up cable moves likewise and rotates the follow-up assembly against the pull of the balance spring S. This moves A down and A′ up. When these ports reach a neutral position (both half open), the air relay and the balanced oil valve are centered, and servo piston movement away from neutral is stopped. Now consider that the control surface movement which the servo has been producing has been bringing the aircraft back to level flight. As the airplane continues toward its normal attitude, the air pick-offs, which have been driven ahead of the gyro box, pass beyond the neutral point and begin to cause servo movement in the opposite direction. This is not opposite control; it is merely the removal of the control originally applied. The mechanism and its ratios are so arranged that the correct amount of control will be applied and also removed at the proper rate as the airplane returns to its normal attitude of flight.

A number of accessories are shown in Figures 230 and 231. T is a suction regulator which keeps the vacuum for spinning the gyro and for the air pick-offs at the proper value regardless of the speed of the suction pump. The vacuum supply is indicated on the vacuum gauge U. The oil sump O carries the reserve oil. V is a filter which prevents foreign matter from being sucked into the system by the oil pump. N is a valve which automatically regulates the oil pressure from the pump and permits it to circulate through the sump whenever the balanced oil valve cuts off circulation to the servo unit. The oil pressure is indicated on the oil gauge W. X is a drain trap


RUDDER KNOB
DIAL ILLUMINATING LAMP
RUDDER FOLLOW-UP CARD
DIRECTIONAL GYRO CARD
BALL BANK INDICATOR
CAGING KNOB
IN TO CAGE
CLUTCH CONNECTION TO RUDDER FOLLOW-UP PULLEY
LIGHTING CIRCUIT CONTACTS
AIR INTAKE
AIR RELAY CONNECTIONS FOR RUDDER CONTROL
AIR OUTLET

RON

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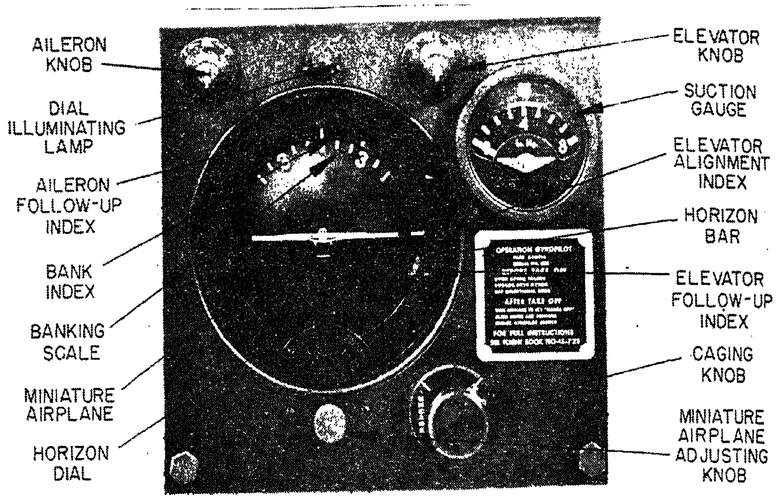
which is used in installations where the balanced oil valve is below the level of the sump. Its purpose is to return the drain oil from the balanced oil valve to the sump. The vent is carried to a point above the level of the oil in the sump. The servo relief valves, shown at P, permit the human pilot to overpower the gyropilot when the system is in operation. The speed control valves, shown at Y, regulate the oil flow from the servo pistons and therefore control the speed with which the gyropilot operates the controls.

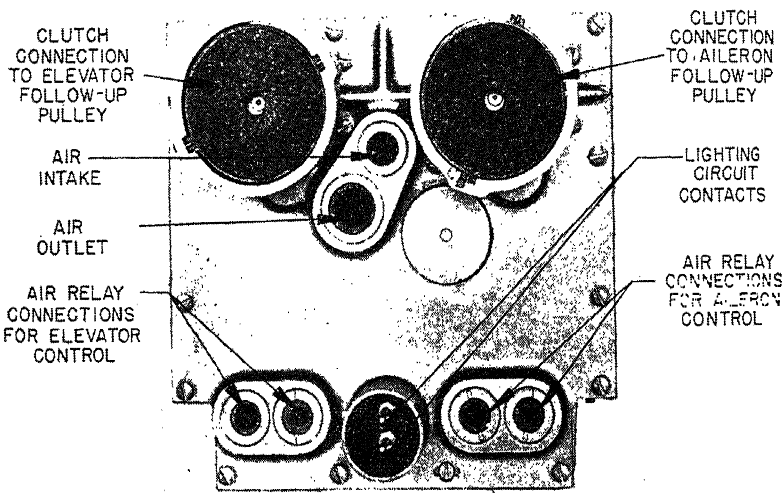
The by-pass valve Z in the servo unit is used to turn the gyropilot on or off. This valve is connected by pulley and cable to a lever which is convenient to the human pilot. When the pilot desires to fly the airplane manually, the valve is opened, oil flows through the by-pass tube, and the controls can be moved freely.

Detail Description

Directional Gyro Control Unit. This unit contains the directional gyro which is the directional reference for both manual and automatic rudder control. It also contains a ball bank indicator, air pick-offs, and a means for setting the gyropilot to hold any selected heading. It is assumed that persons who will use the gyropilot are already familiar with the operating principles and functioning of the directional gyro. In order to have automatic control to a selected heading, it is necessary that the air pick-offs be at neutral when the airplane is headed so as to show the selected reading on the directional gyro. The upper, or follow-up, card is attached directly to the pick-offs, which are at neutral when the readings of the follow-up and the directional gyro cards coincide. Position of the follow-up card is controlled by means of the RUDDER knob at the top. The lower, or directional, card may be set to any desired heading by pushing in and turning the caging knob underneath the dial. The directional gyro control unit, together with the bank and climb gyro control unit, is carried in the mounting unit, and the whole installed as part of the instrument panel. The directional gyro control unit, front and rear, is shown in Figure 232.



FRONT



REAR

Figure 233. Bank and Climb Gyro Control Unit

Bank and Climb Gyro Control Unit. This unit contains the vertical axis gyro which is used for lateral and longitudinal attitude indication and for automatic control of the ailerons and elevators. It also contains the air pick-offs for these two controls, together with the mechanism for setting the gyropilot so that it will fly the airplane at the desired attitude laterally and longitudinally. The circular dial shown in Figure 233 is attached to the gimbal ring of the gyro and therefore provides a fixed horizontal reference as the airplane banks one way or the other. The degree of bank is indicated on the scale at the top of the dial. The horizontal bar in front of the dial is actuated through linkage by a pin in the side of the gyro case so that the bar rises as the airplane noses down, and descends as the airplane noses up, remaining horizontal as the airplane banks.

The position of the miniature airplane in its relation to the horizon bar thus affords the pilot a visual indication of flight attitude of the aircraft laterally and longitudinally. In order to compensate for load conditions, the miniature airplane can be raised or lowered with respect to the horizon bar by means of the small knob underneath the dial. The pointer at the right-hand side of the horizon dial is an alignment index for lining up the elevator follow-up index when the airplane is flying level preparatory to engaging the gyropilot.

By means of the aileron knob, the air pick-offs for lateral control may be set for the desired angle of bank. By means of the elevator knob, the air pick-offs for longitudinal control may be set for the desired angle of climb or glide.

Mounting Unit. The mounting unit consists of a frame to which air relays, balanced oil valves, follow-up pulleys, pressure and drain oil manifolds are attached. The mounting unit is the support for the control units, which slide in place on tracks. All electrical, mechanical, and air connections are established when the control units are bolted in place. The follow-up pulleys, to which the follow-up cables are attached, are provided with clutches which carry their motion to the control units. The pressure and drain manifolds on the bottom of the mount-

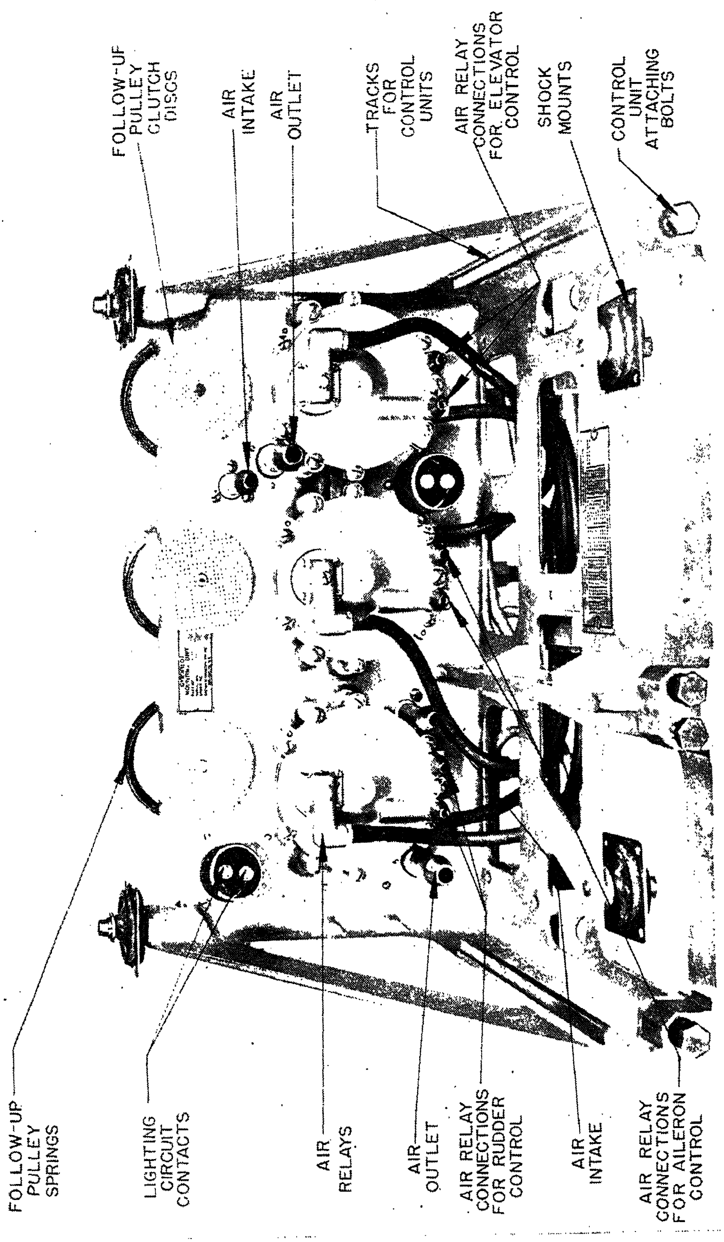


Figure 234. Mounting Unit, Front

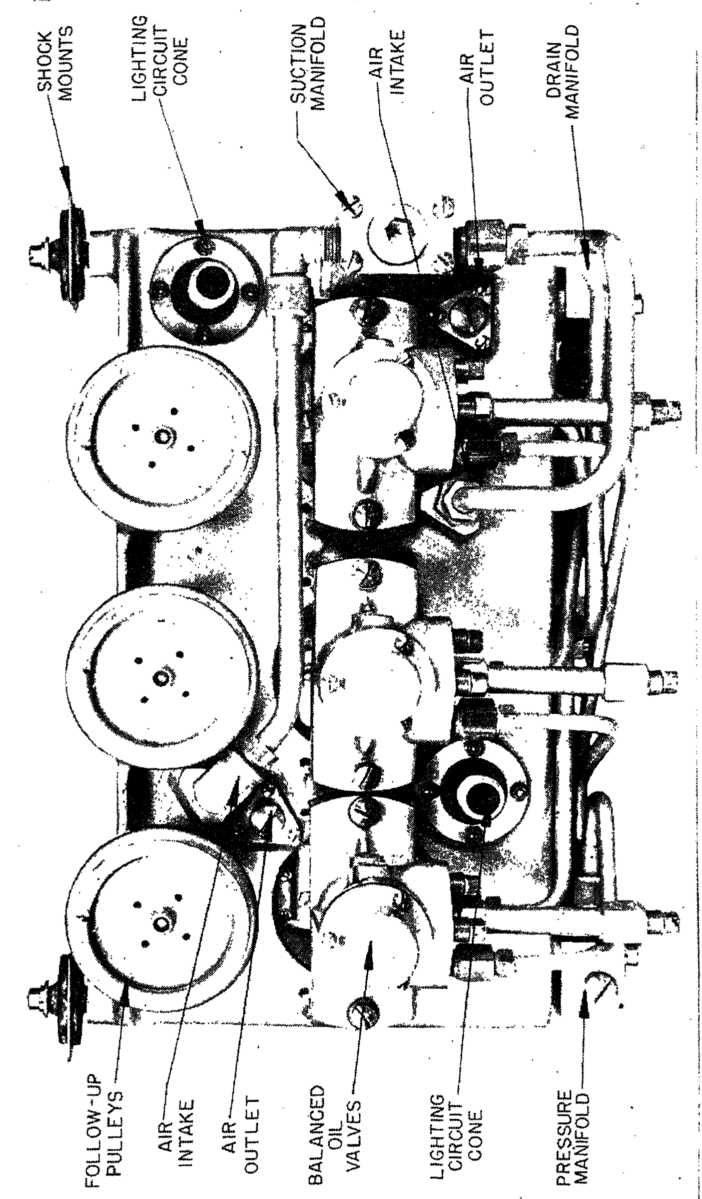


Figure 235. Mounting Unit, Rear

ing unit are piped to the three balanced oil valves and serve to collect the pressure and drain oil at the valves. All air intake connections, both for the air relays and the gyros, are manifolded, permitting the entire system to be connected through one air filter.

Vacuum Relief Valve. Regulation of vacuum to the amount best suited to gyropilot operation is secured through the use of a vacuum relief valve. Since a vacuum pump is to be used which will provide proper vacuum at 1,000 engine r.p.m. and at cruising r.p.m. at high altitude, it is necessary to spill the excess capacity when operating under more favorable conditions of engine speed or altitude. The vacuum relief valve performs this function and holds the vacuum within desired operating limits.

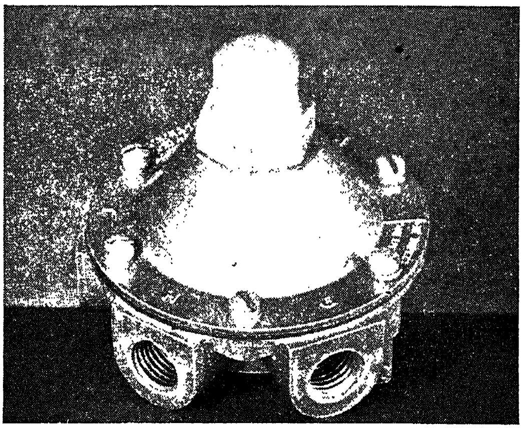


Figure 236. Vacuum Relief Valve

Servo Speed Control Valves. The speed valves serve to control the rate of flow of oil from each servo cylinder to the sump, and thereby to control the rate of response of each servo. The speed valve assembly consists of three identical units (one for rudder, one for aileron, and one for elevator control). The speed valves are connected in the return line from the servo unit to the sump.

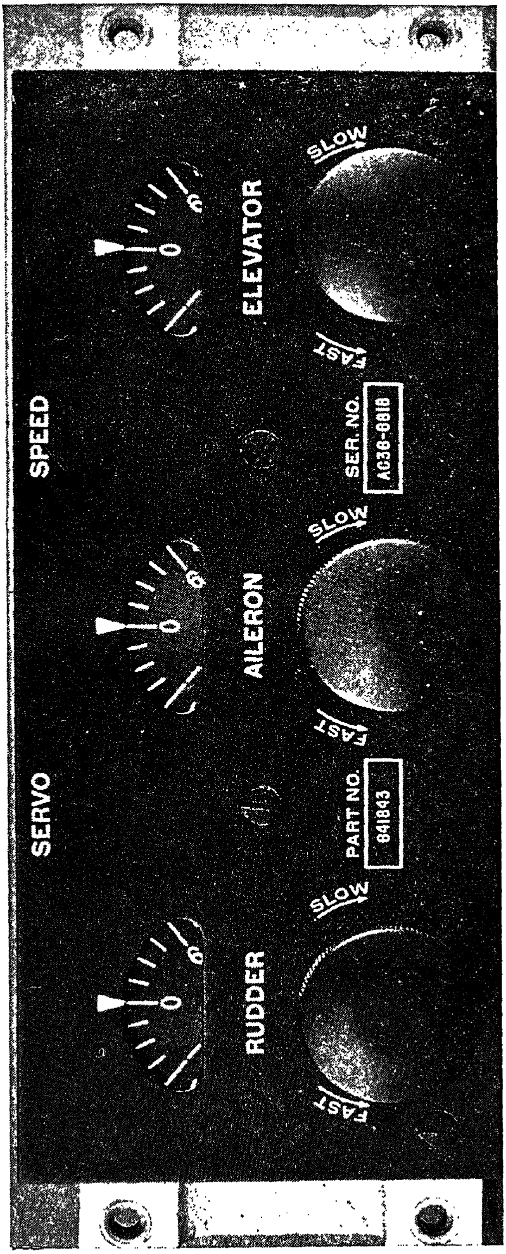


Figure 237. Servo Speed Control Valves

Oil Pressure Gauge. An oil pressure gauge indicates the pressure at which oil is being supplied to the gyropilot. Desired operating pressure varies with different types of airplanes.

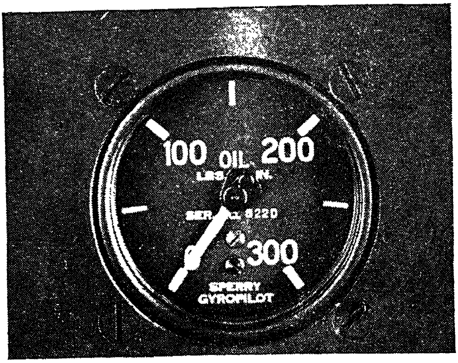


Figure 238. Oil Pressure Gauge

Oil Pump. An engine-driven oil pump provides the necessary pressure and flow of oil for operating the gyropilot. Pumps are made with several types of connections to fit the drives available on various engines.

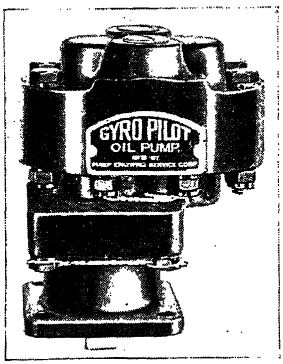


Figure 239. Oil Pump

Vacuum Pump. Vacuum for driving the gyros, and operating the air pick-offs and air relays is obtained from an engine-driven vacuum pump.

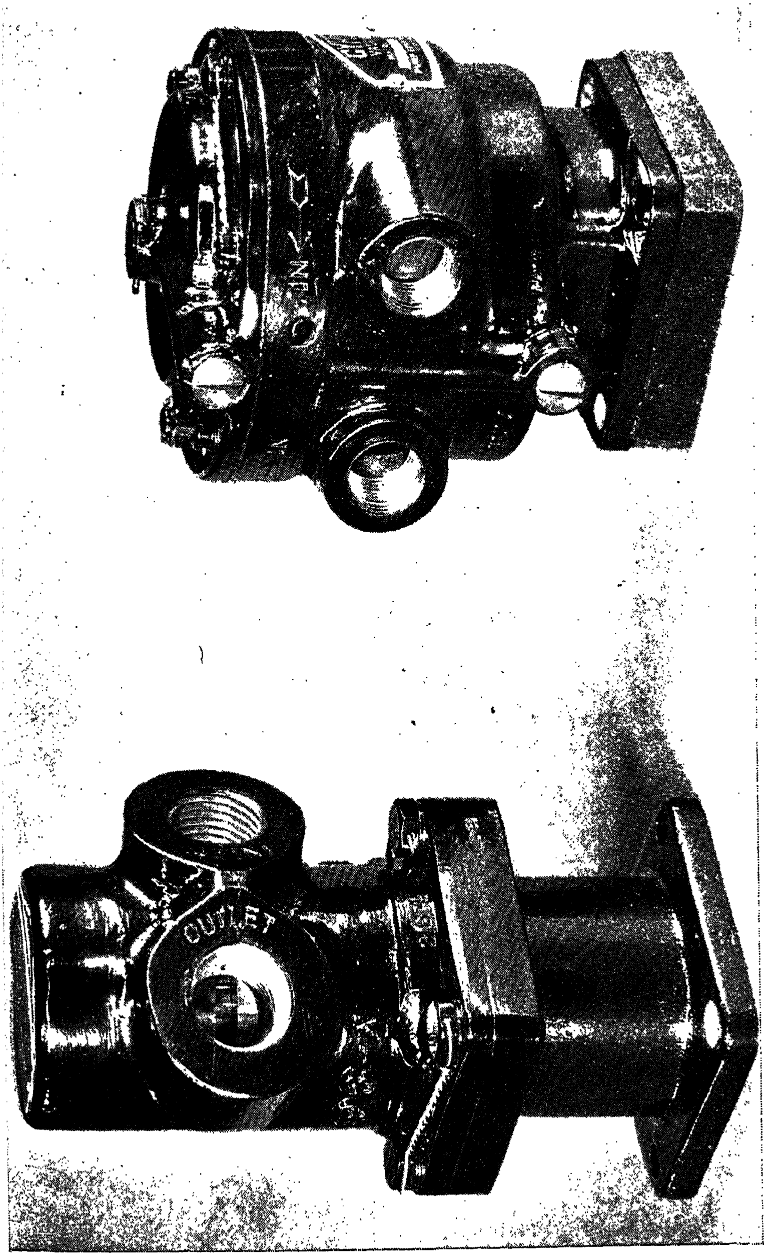


Figure 240. Vacuum Pumps

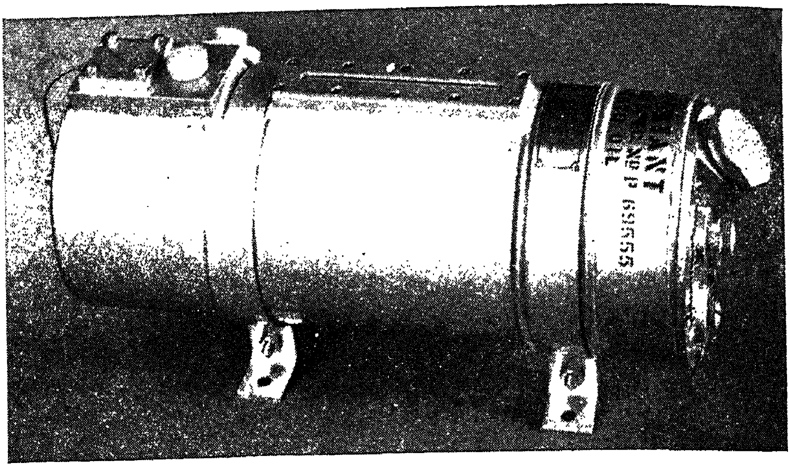


Figure 241. Sump and Pressure Regulator

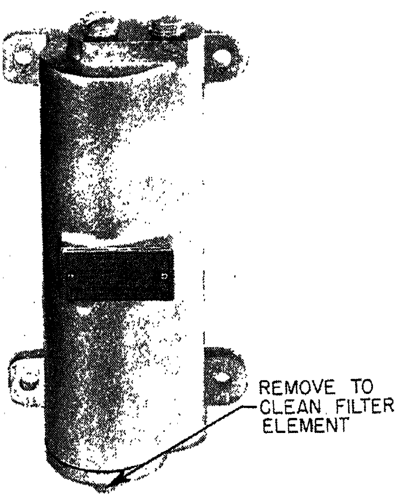


Figure 242. Oil Filter

Sump and Pressure Regulator. This unit is the oil reservoir for the gyropilot hydraulic system. It contains a sight gauge by which the amount of oil in the sump may be ascertained. A pressure regulator, integral with the sump, automatically regulates the oil pressure from the pump and permits it to circulate through the sump whenever the balanced oil valve cuts off circulation to the servo unit. The pressure regulator may be adjusted to the correct pressure for the particular airplane in which it is installed.

Oil Filter. This unit provides a means of maintaining a flow of clean oil through the hydraulic system. The filter element can be withdrawn for cleaning without the necessity of disconnecting any piping or fittings.

Drain Trap. The drain trap is used on installations where gravity drainage of the balanced oil valves is not possible. The

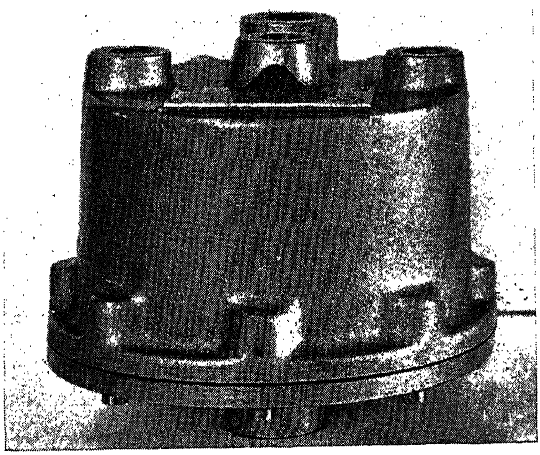


Figure 243. Drain Trap

drain trap contains a float which operates a valve connecting the trap to the suction side of the oil pump when sufficient oil has collected in the trap to lift the float. Before all oil is sucked out of the trap, the float lowers and closes the valve, thus preventing air from entering the pump lines.

Servo Units. Three different types of servo units may be used, depending upon the cable arrangement or space requirements of the particular airplane. The first of these types is a servo consisting of three cylinders cast *en bloc,* with piston rods extending from the cylinders at each end of the unit. This type has a manually operated by-pass valve for engaging or disengaging the gyropilot which affects all three cylinders at once. The servo piston rods are connected directly to the main control cables of the airplane. The second type of servo is similar to the one described above, except that the cylinders are individual instead of being cast *en bloc,* each one having its individual by-pass valve. The third type consists of individual, push-pull type cylinders with piston rods extending from one end only. This type has hydraulically operated by-pass valves, all three of which are controlled by a single "on-off" valve. The fixed end of each cylinder is attached to a stationary structural member of the airplane, and the piston rod end to some part of the control system such as the control column or a bell crank.

Oil pressure is applied to either side of each piston to produce control application in the required direction. Spring-loaded servo relief valves are built into each servo unit, allowing the human pilot to overpower the gyropilot by applying increased force to the controls.

Servo Oil. Servo oil is a specially developed oil which is free from all ingredients which might have an injurious effect upon the system. It will not congeal at very low temperatures, thus allowing free operation of the gyropilot under all conditions. The oil should be purchased from Sperry or strictly in accordance with Sperry specifications. No other kind of oil should be used.

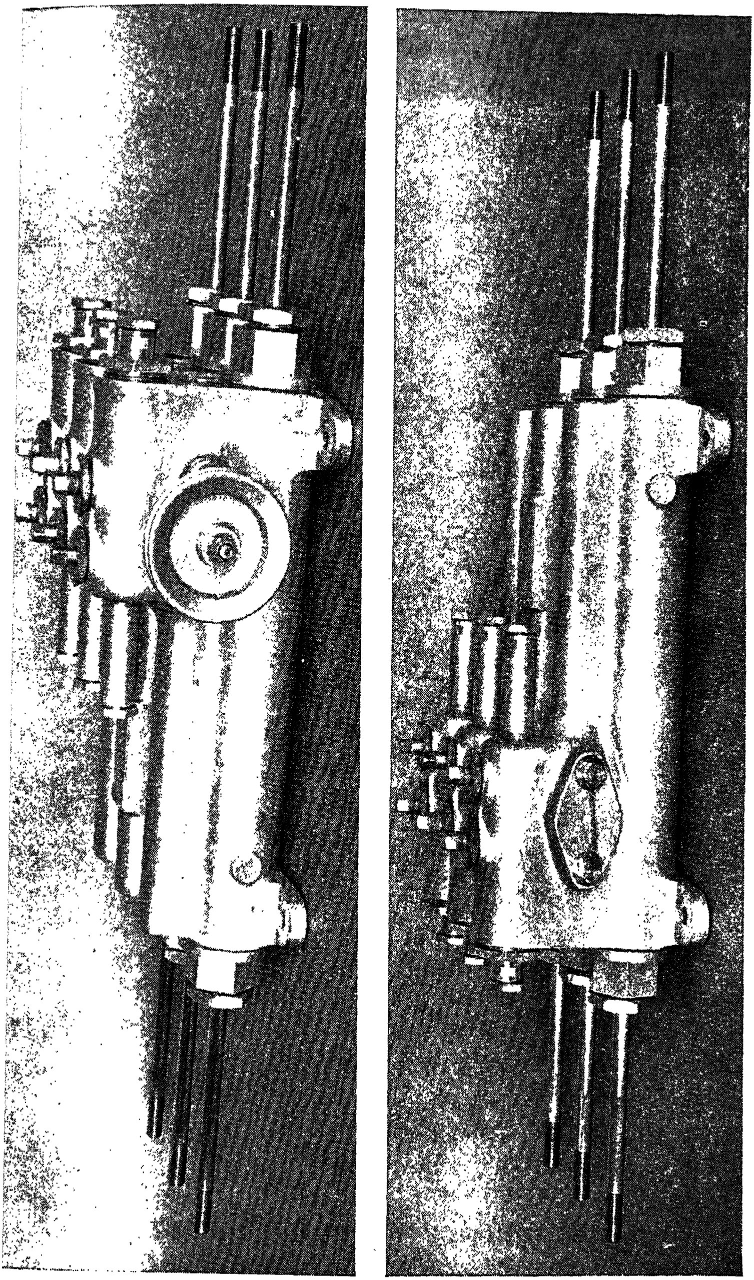


Figure 244. Servo Units

Air Filter. An air filter in the intake line to the gyropilot control units maintains a flow of clean air through the gyros and the air pick-off system. The filter element can be withdrawn for cleaning without the necessity of disconnecting any piping or fittings.

Manifold Block. The manifold block provides a junction between the flexible oil lines from the mounting unit, which is shock mounted, and the rigid oil lines to the servo unit.

Operation

Before attempting to use the gyropilot, the operator should be familiar with its principles of operation and the relation of its component parts as explained in the previous section of this chapter. For those who are thoroughly familiar with the gyropilot the operating procedure is reduced to the following simple routine. Detailed operating instructions are given under Ground Test and Flight Test which are included in this section.

Before Take-off. (a) Check vacuum on run-up—should be 3″ to 5″ Hg.

(b) Check oil pressure—should be within 10 lbs. of recommended pressure.

(c) Uncage bank and climb gyro.

(d) Set and uncage directional gyro.

(e) Engage gyropilot and check operation by rotating each control knob.

(f) Check for air in servo units.

(g) Disengage gyropilot.

Before Engaging Gyropilot in Flight. (a) Trim airplane hands off.

(b) See that servo speed valves are open. Set at 1 if best setting is not known.

(c) Match upper and lower cards of directional gyro control unit, using rudder knob.

(d) Set aileron follow-up index to match zero mark on banking scale, using aileron knob.

(e) Set elevator follow-up index to match elevator alignment index, using elevator knob. *Caution:* Do not align elevator follow-up index with horizon bar, as relative movement between elevator alignment index and horizon bar is in opposite directions.

(f) Engage gyropilot.

Flying with Gyropilot. (a) Set servo speed valves for desired speed of control. Turn down for any control to stop oscillation.

(b) Change course by *slowly* turning rudder knob. Set in bank with aileron knob if turning large amount.

(c) Set desired fore-and-aft attitude with elevator knob.

Do Not's. (a) Do not engage gyropilot when follow-up indices are not lined up.

(b) Do not make course and attitude changes with rapid knob movements. Turn slowly and smoothly.

(c) Do not allow airplane to get too far out of trim.

(d) Do not forget that gyropilot can be overpowered.

Operating Limits. The control gyros should be uncaged whenever the engines are running, except during acrobatics or during maneuvers which would exceed the operating limits of the instruments. These limits are 50° from the vertical for the bank and climb gyro control unit and 55° for the directional gyro control unit. When the engines are not running, keep the gyros caged.

Ground Test. No gyropilot installation should be flown until it has passed a satisfactory ground test. An installation which does not check satisfactorily on the ground cannot be expected to perform satisfactorily in the air. The ground test will catch any reversed connections not caught during the installation inspection.

Fill the oil sump tank ¾ full, close speed control valves, and turn the gyropilot OFF.

Start the engine and run at 600 to 700 r.p.m. and note whether the oil pressure gauge and the vacuum gauge indicate.

Within one or two minutes the oil pump should prime and indicate pressure. *Do not allow the pump to run dry more than five minutes.*

After it is certain that the vacuum and oil pumps are operating smoothly, run at 1,000 r.p.m. and set vacuum regulator for 4½″ of mercury at the gauge and the oil pressure regulator for the pressure it is believed will prove satisfactory. The speed valves should be closed while the oil pressure adjustment is being made.

The vacuum should not be less than 3″ of mercury at 1,000 r.p.m. or more than 5″ of mercury with engine at maximum ground r.p.m.

Open speed valves at least four turns. Each numeral represents one turn of the knob.

Center the controls, align the follow-up indices, and then operate the controls manually, moving them slowly from hard over to hard over independently and collectively a few times. Then hold each control at each extreme position for at least 30 seconds two or three times. This allows time for air in the servo to be pushed through the system by oil flow until it reaches the sump.

Shut down engines for a few moments to check for air in the servos and replenish oil in the sump which will have been passed on to the rest of the system. To check for air in the servos turn the gyropilot ON (engines not running), in which case the controls should act as though locked. A resiliency indicates air in the servo which is compressed as force is applied to a control and which expands as force is removed. Do not confuse stretching of cable with air in the servo. If any doubt exists, observe the indices on the control units for movement when checking for air. Fill the sump ¾ full before continuing with the ground test.

Adjust the servo relief valves properly.

Start engines and run at 1,000 r.p.m. Center all three controls, uncage gyros, open speed valves, align the follow-up indices with the gyro indications, and turn the gyropilot ON. All three controls should remain in position. (If the airplane is not level, the bank and climb gyro will move slowly toward

the correct indication of the attitude of the airplane and cause the elevator and aileron controls to follow. The controls can then be recentered by rotating hand control knobs.)

Check for *direction of control* movement by moving each setting knob back and forth a small amount, ascertaining that each control moves in the direction marked at the knob.

Check for control speed balance as follows: Open all three speed control valves wide. Turn the gyropilot OFF for a moment and move the aileron control hard over. Turn gyropilot ON quickly and count seconds for the wheel or stick to come to neutral. Repeat from the opposite side. Time of return should coincide within 25%. Follow same procedure for rudder and elevator. Up elevator may be considerably slower than down elevator, especially on large airplanes due to the weight of the surface helping down movement and opposing up movement. *Caution:* Be sure that the tail of the airplane is not caused to rise when the elevator control is pushed all the way forward.

Check to be sure that the gyropilot can be overpowered with the gyropilot ON.

If the above tests show proper operation, the equipment is ready for flight test. Should any faulty performance result, correct in accordance with "Trouble Shooting," before proceeding with the flight test.

Flight Test

Uncage bank and climb gyro and set and uncage directional gyro before take-off.

Fly the airplane manually to 2,000 feet or more above ground level, observing the bank and climb gyro and directional gyro to see that they are indicating properly as flight instruments.

Engaging the Gyropilot in Flight. (a) Be sure both control gyros are uncaged.

(b) Check vacuum. The desired vacuum is 4″ of mercury. It should be not less than 3″ or more than 5″.

(c) Check oil pressure. The oil pressure should be within 10 lbs. of recommended operating pressure for the airplane.

(d) Trim the airplane for "hands off" condition.

(e) Open servo speed control valves. A closed speed valve locks its control in position when the gyropilot is ON. Therefore, it is important that the valves be open prior to engaging the gyropilot.

(f) Check directional gyro control unit setting.

(g) Set follow-up indices to coincide with gyro indications. Rudder follow-up card should match directional gyro card; aileron index should match mark at top of bank and climb gyro dial; and elevator index should match elevator alignment index at side of dial. *Caution:* Do not align elevator follow-up index with horizon bar, as relative movement between elevator alignment index and horizon bar is in opposite directions.

(h) Engage gyropilot slowly. By holding the controls as the gyropilot is engaged, the pilot can feel when the gyropilot is flying the airplane.

Speed Control Valve Setting. When the gyropilot is engaged there may be an oscillation of one or more of the controls with the speed control valves wide open. The valve corresponding to the oscillating control should be slowly turned toward closed position until the oscillation ceases. After the speed valve has been closed enough to stop oscillation in a control, the setting knob for that control should be moved back and forth a small amount to be sure that control operation has not been stopped by closing the speed valve too far. Speed valve settings should not have to be changed unless it is desired to increase materially the speed of control in rough air. The numbers on the valve dials represent turns of the valve and may be used as a reference for bringing the valve back to a desired setting. When there is no oscillation present, speed control valves should be left wide open, unless reduced speed of control is desired. When proper adjustment is obtained for all three controls, the airplane should not yaw, pitch, or roll more than 1° (plus or minus) from the set course. There should be no overcontrolling or hunting of the control surfaces. If the

ailerons are hunting, they will cause a yaw, even though they do not move enough to cause a wing to drop. Adjustment of the aileron speed control valve will usually correct this. *Caution:* Turning any of the three speed control valves to its "OFF" position locks the corresponding control surface in whatever position it happens to be and should be avoided.

Now fly at an altitude where there are many varying air currents, and observe whether or not the settings of the speed control valves require changing in order to improve the flying. Repeat the previous tests to determine the best settings, and compare the results obtained in rough air with those obtained in calm air.

Note: In both of the above tests have the airplane flown manually with as much precision as possible, long enough to obtain a comparison between manual and automatic control. In watching the natural horizon for a check on the elevator performance, do not confuse vertical bumps with pitching.

Directional Control. Directional control in the gyropilot is based on the directional gyro which must be set with the magnetic compass and rechecked at periodic intervals. The average drift of a directional gyro should not be more than 3° in 15 minutes. A drift of 5° in 15 minutes is permissible on one heading, providing the average on the four cardinal headings does not exceed 3° in 15 minutes. Since the gyropilot controls to a set heading on the directional gyro, the drift will cause a corresponding change in the magnetic heading of the airplane. When the airplane is only 2° or 3° off the desired heading by magnetic compass, a small adjustment of the rudder knob will suffice to correct the heading. When there is an appreciable difference in reading between the compass and directional gyro, the gyropilot should be disengaged for a moment while the directional gyro is being reset.

After flying a straight, level course with the gyropilot on a cardinal heading for about 10 minutes, note difference in readings between directional gyro control unit and magnetic compass. An average error of 3° in 15 minutes is not excessive. If the gyro drifts more than this, it may be caused by excessive

vibration, and the shock-absorber suspension of the mounting unit should be inspected and corrected. The amplitude of vibration should not be more than 0.004″ in any direction when measured with a vibrometer at the control units.

Lateral Control. Lateral control in the gyropilot is taken from the bank and climb gyro. The aileron knob can be set for either level flight laterally or to any angle of bank up to 30° for use in a caged gyro turn or where the turning is controlled by continued manual operation of the rudder knob.

Longitudinal Control. The desired longitudinal attitude of the airplane may be adjusted up or down by means of the elevator control knob in the upper right corner of the bank and climb gyro control unit.

Slow Speed Test. Retard engine speed to approximately 1,000 r.p.m., nose the airplane into a glide, and observe the performance of the automatic control. At this speed, all controls should function perfectly. Retard engine speed still further and note the speed (in r.p.m.) at which the automatic control starts to become sluggish.

Slow Turn Test. A slow turn of 180° will cause the bank and climb gyro to precess slightly from the vertical. The effect is reversed as the turn is continued for another 180°, virtually cancelling the original displacement. For a turn in either direction, the horizon bar will descend slightly, causing the gyropilot to correct for an apparent climb. The airplane will thus lose altitude for a short time and will return to level flight as soon as the horizon bar regains its normal position, which will be in about the same length of time it took to make the turn. The horizon bar will also tilt slightly one way or the other, depending on the direction of the turn.

Start the test with airplane flying straight and level. Make a slow turn by rotating the rudder knob, and when 180° is reached, level up the airplane with the control knobs, using indications of the other instruments or observing the natural hori-

zon. Then note the amount (estimated in degrees) that the horizon bar is displaced.

Make a 360° turn and note whether the horizon indication is normal upon completion of the turn. Make the slow turn test in the opposite direction. The tilt of the horizon bar should be approximately the same in amount although in opposite directions.

Maneuvers. Outside of straight flight, which may be either level or climbing or descending, the only maneuvers that it should be necessary to perform with a gyropilot are turns and spirals. Course changes of a few degrees may be made as flat turns, in which case it is only necessary to rotate the rudder knob slowly until the airplane reaches the new heading.

Normal Turns. Place the airplane in a 15° to 20° bank by turning the "aileron" knob on the control unit in the desired direction. The banking reference marks at the top of the bank and climb gryo dial are graduated in 10° steps up to 50° each side of the vertical. Immediately rotate the "rudder" knob at such a rate that the ball in the ball bank indicator remains centered. If the airplane tends to nose up or down slightly this can be corrected with the "elevator" knob. As the desired new heading is approached, rotation of the rudder knob should be stopped and the airplane leveled out by means of the aileron knob.

Spirals. Spirals may be made in the same manner as turns, the airplane being nosed up or down as required by means of the "elevator" knob. A convenient method of making spirals is to cage the directional gyro, offset the upper card a few degrees depending upon the rate of turn desired (10° gives maximum turn) by turning the control knob in the direction desired. Then center the ball by means of the aileron knob, and control the rate of ascent or descent by means of the elevator knob. In using this method, *no quantitative directional* reference is available, as the gyro is caged. To resume normal flight, *uncage* the directional gyro and level the airplane by turning the aileron and elevator control knobs.

Use of the Airplane Trimming Control. Changes in flight attitude, power, altitude, and load shifts will affect the fore-and-aft trim of the airplane and cause the gyropilot to hold the elevator against the out-of-trim condition so as to hold the airplane to the set-in attitude. This may result in an oscillation of the elevator control. The trim of the airplane can be checked by disengaging the gyropilot for a few seconds and noting whether the airplane tends to nose up or down. A trim correction should then be made with the elevator trimming tab or stabilizer.

On airplanes equipped with individual by-pass valves for each servo, only the elevator control need be turned off to check trim. When by-passing a single servo cylinder, close the speed control valve to that control so that oil pressure to the other two controls will not be by-passed. In rare cases, better control may result with a slight loading of the elevator control in one direction. In order that the human pilot will not have to apply a large force to the elevator to hold the airplane when the gyropilot is disengaged, the airplane should be kept approximately in trim during gyropilot operation.

Manual Control. When it is desired to resume manual control, it is only necessary to move the engaging lever to the OFF position and take over the controls. As an added safety measure, servo relief valves are provided so that the human pilot can overpower the gyropilot by applying about twice normal force on the controls.

Final Tests

On completion of flight tests, a final inspection of the entire installation should be made. Check for oil leaks, stretched cables, and loose pulley mountings. Check oil in sump and refill if necessary.

Maintenance

Cleaning and Lubrication. Parts which require cleaning are covered in the overhaul check periods which follow. The

internal parts of the control units will require cleaning and oiling only at the 600–800 hour check period when they are removed from the airplane and completely overhauled. The only other lubrication required in the entire system is to refill the sump and to oil the follow-up pulleys as directed in the 50–100 hour check period, below.

Adjusting. Adjustments to vacuum relief valve, oil pressure regulator, and other parts of the equipment are given where necessary under Trouble Shooting. Adjustments which may be made during flight, such as speed control valve, directional gyro drift, lateral control, etc., are given in the section on Operation. Instructions for the adjustment of the servo relief valves and the balanced oil valves are given under the 300–400 Hour (Engine Overhaul) Period.

Periodic Inspection and Maintenance. The purpose of any inspection and maintenance is to forestall trouble or failure by detecting maladjustment, wear, or weakness before it becomes serious and to make the necessary correction to prevent a failure of the apparatus. The inspection periods mentioned can only be suggestive, since their actual required frequency will depend largely on the service to which the apparatus is subjected. It is suggested that the minimum periods be used, until the user becomes thoroughly familiar with the apparatus.

50–100 Hour Check

Inspect all piping and fittings including flexible hoses. Tighten or replace fittings or pipes where necessary to stop leaks. Replace any flexible hoses showing signs of seepage at connections or pimples on surface of hose. Tighten servo packing nuts if there is any leakage. *Caution:* Do not tighten excessively, as packing leathers are pressure-sealed and excessive tightening will produce binding on servo rod.

Inspect all cables, cable connections and pulleys. Main cables, follow-up cables and servo ON-OFF cables should be free working, positive, and free from any signs of fraying or wear.

Check follow-up pulleys on mounting unit with gyro control units removed, and oil springs, if dry. A few drops of engine oil are sufficient.

Inspect and replace if necessary air filter element in the air filter and clean air intake screen in vacuum relief valve.

Drain oil in sump tank. Remove filter element from the oil filter, clean in gasoline, and replace. Refill sump with new oil. Should be ¾ full. Use Sperry servo oil, P-69555.

Ground test as previously noted (Ground Test).

300–400 Hour (Engine Overhaul) Period

Perform all operations called for in 50–100 hour check.

Remove gyro control units and have bench check made in instrument shop. Overhaul if performance is not satisfactory. Replace rubber grommets if necessary.

Drain oil sump.

Remove strainer from sump, clean in gasoline, and replace.

Remove oil and vacuum pumps. Wash in gasoline and inspect driving end for wear. Check freedom of rotation. Do not disassemble the pumps unless absolutely necessary. If facilities are available, have pumps checked for performance.

Inspect shock-absorbing bushings on mounting unit and replace if necessary.

To Check Servo Relief Valves for Blow-Off Pressure. Double-End, Cast En Bloc Type. The conditions which govern the setting of the servo relief valves are (1) they should open readily in either direction without excessive manual effort to overpower the gyropilot, and (2) they should not open during normal flight conditions in smooth or rough air. The best setting to meet these conditions will usually be found between 75% and 100% of gyropilot operating pressure. To set the relief valves tee in two oil pressure gauges of 300-lb. range, one in each line, to the servo cylinder at the point where the lines from the balanced oil valves are normally attached. If it is not convenient to connect the gauges at the servo, connect them to the extra plugged outlets on the manifold block forward of the mounting unit.

Center controls, align follow-up indices, open speed valves, and turn gyropilot "On." See that vacuum gauge indication is normal, and that the oil pressure, as indicated by the gyropilot oil gauge, is adjusted to give satisfactory operation under normal conditions.

Rotate gyropilot hand control knob corresponding to the control being adjusted until the control surface has reached its stop. Continue rotating control knob beyond this point until the follow-up indices are approximately 10° apart. This will leave a signal on the control and hold the balanced oil valve open, thereby reducing the back pressure on the return side of the servo to a minimum. Note readings on the test gauges. Remove hexagonal end cap, at the end of the servo unit at which the greatest length of rod is visible. If the differential pressure (difference between the gauge readings) is equal to the indicated gyropilot oil pressure, insert a screwdriver and turn the adjusting screw counter-clockwise until the differential pressure is approximately 75% of the gyropilot operating pressure. If the differential pressure is lower, turn the adjusting screw clockwise until the difference between the gauge readings is approximately 75% of the gyropilot pressure. Then replace hexagonal cap.

Rotate gyropilot control knob in opposite direction to move control surface hard over against the opposite stop. Adjust the other relief valve for the same servo cylinder in the manner described in the previous paragraph.

To check the adjustment for each direction of control, rotate control knob until control surface is centered. Then manually overpower the control first one way and then the other, noting whether the differential pressures on the test gauges are approximately equal for each direction of control movement. If it is found after flight tests that the valves open during normal flight conditions in smooth or rough air, it will be necessary to reset them to open at a differential pressure which pressure will be a higher percentage of the normal gyropilot operating pressure.

When proper adjustments are obtained, work air out of system in accordance with instructions.

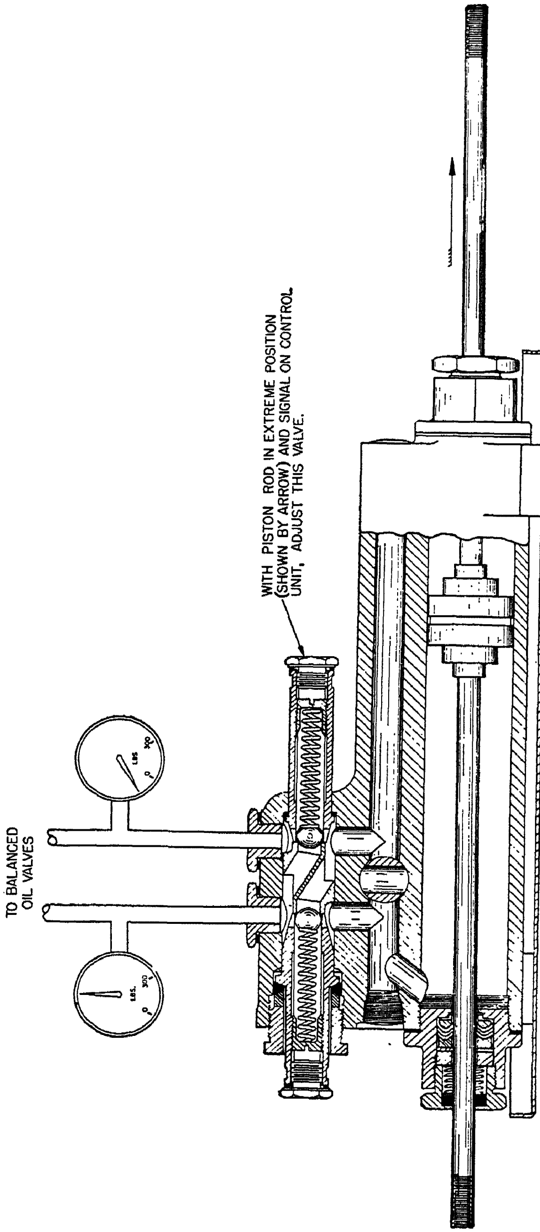


Figure 245a. Cross-Section, Servo Unit, Double-End Type, Showing Relief Valves

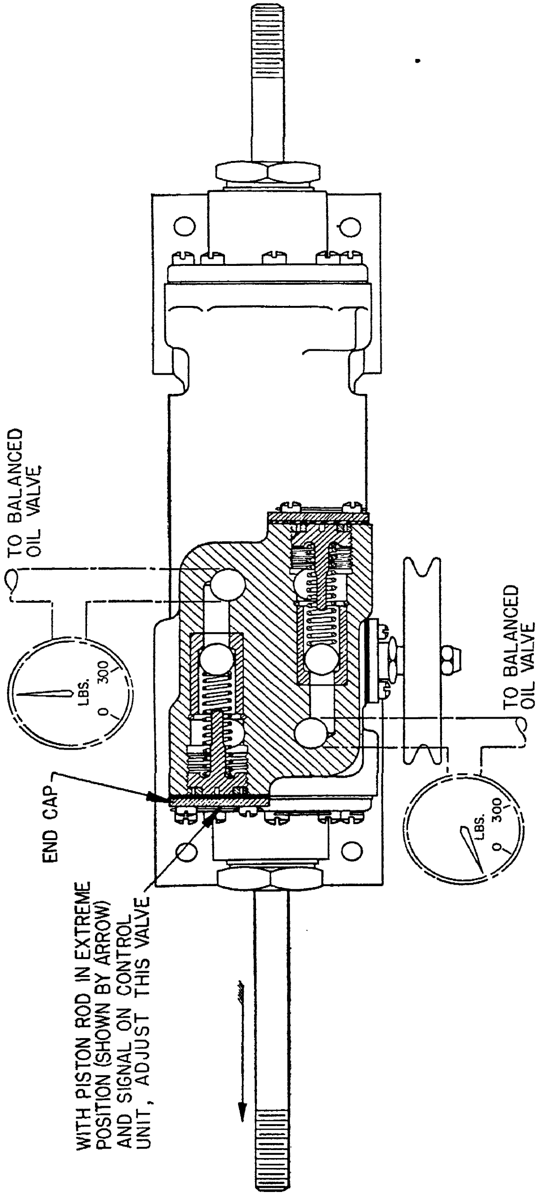


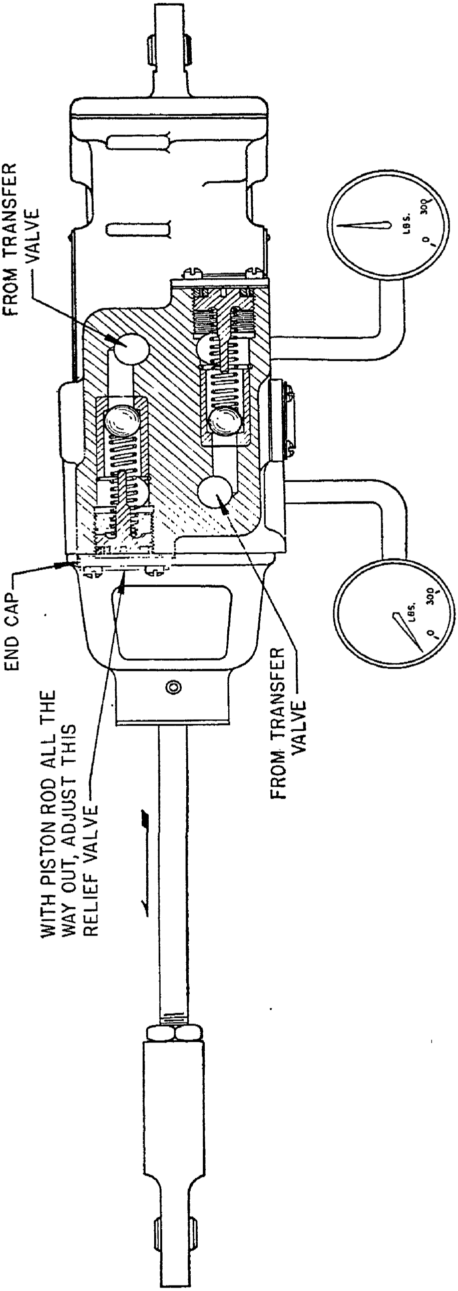
Figure 245b. Cross-Section, Servo Unit, Double-End Individual Type, Showing Relief Valves

If it should be necessary to tighten relief valve packing gland nut in order to prevent oil leakage, hold the relief valve tube with a wrench on the flats to keep the tube from turning.

DOUBLE-END, INDIVIDUAL TYPE. The instructions for this type of servo are the same as those above, except that in the case of the individual servo unit the relief valves are as shown in Figure 245b. These relief valves have end plates with four attaching screws, instead of the hexagonal, threaded end caps of the tubular type relief valves.

PUSH-PULL HYDRAULIC BY-PASS TYPE. For this type of servo unit, refer to Figure 246. The relief valves are the same as those in the double-end, individual type servo shown in Figure 245b. For convenience, the pressure gauges may be connected at the tapped holes in the side of the servo as shown in Figure 246.

Freedom of Balanced Oil Valves. Check freedom of balanced oil valves and air relays and centralization of balanced oil valves. The location of the balanced oil valves on the mounting unit is positively fixed. The air relays can be shifted slightly by the amount of clearance between the mounting holes and the mounting screws. After the balanced oil valve and air relay are both individually checked for free working, the air relay may be mounted loosely and shifted about on the screws until the two units together operate freely. Freedom of the two units can best be checked with the rear cover of the balanced oil valve removed. If the balanced oil valves are centralized properly, there should be no movement of a control with the gyropilot turned ON (oil pump operating) and the gyro control units removed. Connect a rubber tube to one of the air relay connections. With oil pressure ON and gyropilot engaging lever ON, light suction and pressure should produce movement of the controls in each direction, which movement should cease when pressure or suction is removed. If the movement of the controls continues after the pressure or suction is removed, the balanced oil valves are not centralized. To centralize a balanced oil valve, proceed as follows:


FROM TRANSFER VALVE
END CAP
WITH PISTON ROD ALL THE WAY OUT, ADJUST THIS RELIEF VALVE
FROM TRANSFER VALVE
LBS.
0
300
LBS.
0
300

Cro

To Centralize a Balanced Oil Valve. With wrench T-27407 loosen centralizer locknut E, Figure 247, and adjust centralizer nut D until corresponding control just starts to move in one direction; mark position of centralizer nut with respect to valve body. Then turn centralizer nut in the opposite direction

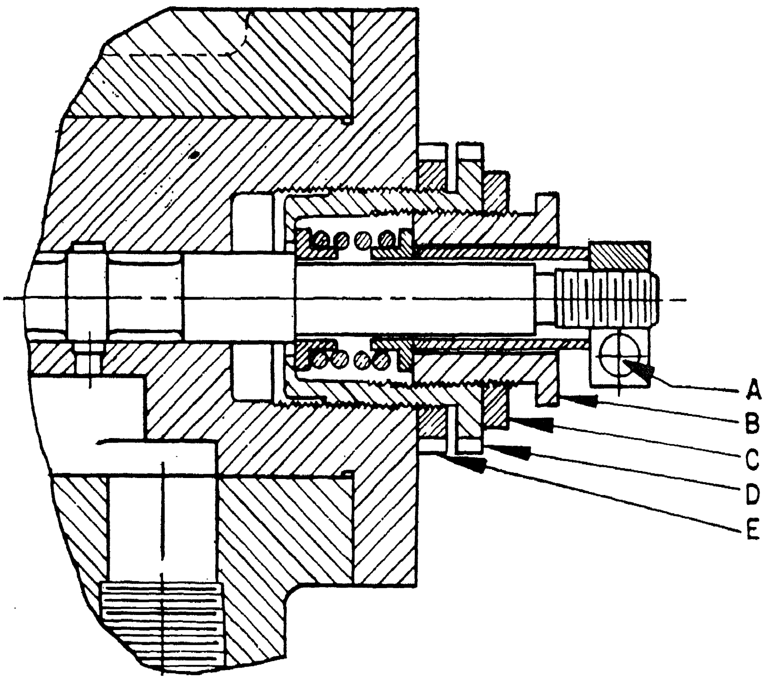


Figure 247. Cross-Section, Balanced Oil Valve

until control starts to move in the opposite direction, and mark. Now turn centralizer nut midway between the two markings, and tighten the centralizer locknut. *Important:* Care must be taken not to disturb the plunger nut, spring nut, and jam nut, A, B, C, in Figure 247.

To Adjust for End Play. If it is found that there is end play or initial compression in a balanced oil valve it will be necessary to remove the valve core assembly and readjust. To

do this, first remove the air relay, being careful not to damage the shaft when detaching it from the balanced oil valve core. Loosen centralizer locknut E with T-27407 and back out the valve core assembly by turning centralizer nut D counter-clockwise. With wrench T-33959 loosen centralizer jam nut C while holding centralizer spring nut B with wrench T-33958. Screw centralizer spring nut and jam nut assembly *out* until there is noticeable play; then screw the assembly *in* until the end play just disappears. Tighten centralizer jam nut with wrench T-33959 while holding centralizer spring nut with T-33958 and centralizer nut D with wrench T-27407.

Loosen plunger nut lockscrew A and turn plunger nut counter-clockwise until there is noticeable play between the plunger and the centralizer assembly; then screw plunger nut in until end play just disappears. When these adjustments are completed, there must be *no play,* and at the same time, the spring must be *under no initial compression.*

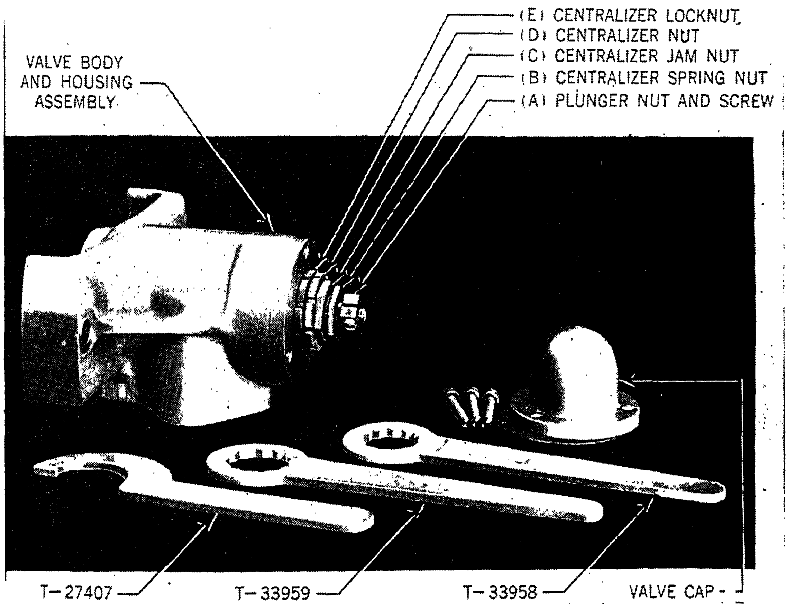


Figure 248. Balanced Oil Valve, End Cap Removed for Centralizing

Replace the valve core assembly in the valve body and screw in the centralizer nut until the end of the valve core is flush with the air relay end of the valve body. Replace air relay and centralize the balanced oil valve as directed above.

The wrenches, T-27407, T-33958, and T-33959, are specially designed for these operations and may be obtained from the Sperry Gyroscope Company.

Ground test as previously noted.

600–800 Hour Period

Note: Operations recommended at this time should only be performed by organizations trained in the overhaul of gyro-pilot equipment and having the necessary special tools and fixtures required.

The following units should be removed and overhauled to put them in first-class operating condition.

(a) Directional Gyro Control Unit
(b) Bank and Climb Gyro Unit
(c) Balanced Oil Valves
(d) Oil Sump
(e) Pressure Regulator
(f) Oil Filter
(g) Oil Pump
(h) Vacuum Pump

The following units should be removed and tested but not disassembled for overhaul unless their performance is not satisfactory.

(a) Air Relays
(b) Speed Control Valves
(c) Vacuum Relief Valve
(d) Servo Unit

The construction of these units is such that there is little chance of internal wear.

Re-install all units and make all checks recommended for the more frequent periods.

Ground test as previously noted.

Trouble Shooting

In order to obtain ground test at all, it is necessary to have the proper vacuum, oil in the sump, and oil pressure. Possible causes of vacuum and oil troubles are listed below and followed by other troubles which might occur when vacuum and oil pressure are sufficient.

Low or No Vacuum (Under 3″ Hg)

Causes	Remedies
(a) Vacuum relief valve set too low.	Screw *in* adjusting screw. If increased vacuum does not result, valve is defective or trouble lies elsewhere. If vacuum does not jump with hand held over air intake of valve, trouble is definitely elsewhere.
(b) Pump failure.	Repair or replace pump. Be sure that some other defect in the installation is not responsible for pump failure.
(c) Leak or break in vacuum line.	Locate and repair.
(d) Obstruction in vacuum line (may be collapsed inner wall of flexible hose).	Locate and repair.
(e) Excessive line drop.	Tee a suction gauge into the pump end of the vacuum line. With a suction of 7″ mercury at the pump, it should be possible to obtain 4″ mercury at the gyropilot. (Vacuum at the pump should not exceed 10″.) If there is evidence of excessive line drop, recheck the installation in accordance with vacuum system installation instructions (Air System).
(f) Pump lines reversed. (If a check valve has not been installed, the control units will be damaged by oil from the pump discharge.)	Check installation and connect lines correctly.

Excessive Vacuum (Over 5″ Hg)

Causes	Remedies
(a) Vacuum relief valve set too high.	Reset.
(b) Air intake filter clogged.	Replace with new filter element.
(c) Vacuum relief valve stuck closed.	Remove screen and push valve free with finger. Replace screen. If sticking persists, replace or repair.
(d) Shipping plug not removed from inlet end of air filter.	Remove plug.

Low or No Oil Pressure

Causes	Remedies
(a) Insufficient oil in system.	Fill sump ¾ full. After running engine 5 minutes with servo speed control valves open, refill to make up for oil fed into the system.
(b) Pressure regulator out of adjustment.	Adjust with speed valves closed. Remove cap and loosen locknut. Screw *in* to raise pressure, *out* to lower pressure.
(c) Pressure regulator dirty or defective.	Clean, or repair and readjust.
(d) Pump intake line or filter clogged.	Check line and filter.
(e) Defective oil pump.	Test and replace if necessary.
(f) By-pass valve open.	Close by-pass.
(g) Broken line or leak.	Locate and repair.

Excessive Oil Pressure

Causes	Remedies
(a) Oil pressure regulator set too high.	Adjust with speed valves closed. Remove cap and loosen locknut. Screw *out* to reduce pressure.
(b) Oil pressure regulator stuck.	Clean and readjust.

Foaming of Oil. Foaming of oil is invariably caused by a leak in the line leading from the sump to the oil pump inlet or by a leak in the pump itself. In either case, the leak is not usually externally apparent. Being on the suction side of the system, *air* leaks *in* instead of *oil* leaking *out*. Air mixes with

the oil, creating a foam which is of much greater volume than the oil itself. The excess volume is discharged from the sump vent, causing loss of oil from the system.

NO OPERATION OF ANY CONTROL. Failure to operate all three controls in either direction can be attributed to the following causes:

CAUSES	REMEDIES
(a) Low or no oil pressure.	See "low or no oil pressure" paragraph.
(b) Low or no vacuum.	See "low or no vacuum" paragraph.
(c) Engaging lever OFF.	Set to ON.
(d) Gyropilot OFF due to reversed or broken connection between ON-OFF control and servo.	Check for full 90° throw of valve at servo. With engines not running, controls should be free with gyropilot OFF and feel locked with gyropilot ON.
(e) Speed control valves closed.	Open speed control valves 2 to 4 turns.

FAILURE OF ONE OF THE CONTROLS

CAUSES	REMEDIES
(a) Speed valve closed.	Open speed valve.
(b) Servo relief valve by-passing.	Reset valve in accordance with instructions given above.
(c) Balanced oil valve on mounting unit stuck.	Remove rear cap and work valve back and forth by hand with oil pressure on, gyropilot off.
(d) Defective control unit (*Note:* If light sucking and blowing on the air relay produces control operation, the trouble is probably in the control unit.)	Replace—examine control unit for condition of rubber grommets at rear.
(e) Air relay stuck.	Clean or replace.

CONTROLS HUNTING

CAUSES	REMEDIES
(a) Air in oil system.	Move controls back and forth manually with engine running and gyropilot OFF. Hold each control at one and then the other extreme position for one minute. This permits con-

Controls Hunting (*Continued*)

Causes	Remedies
	tinuous flow of oil down one servo line, through the by-pass and into the other line, thus carrying any air back to the sump via the exhaust line. The follow-up indices should be set neutral at the start with the controls at neutral.
(b) Lag in follow-up cable hookup caused by friction which would eventually return the follow-up to datum too late and cause overtravel, thereby reversing control.	Examine follow-up system cable and pulleys to see that follow-up indices are dead beat with controls. Remove any lag present.
(c) Sticking oil valve.	Work valve manually until free—then hold at each extreme position for about 2 minutes to allow any dirt to be carried back to the sump. This to be done with gyropilot engaging lever in Off position.
(d) Unbalanced oil valve.	Reset valve to neutral.
(e) End play in oil valve.	Reset balanced oil valve in accordance with instructions given.
(f) Gyros caged. A caged gyro will precess back and forth against the caging stops, causing the controls to follow.	Uncage gyros.
(g) Incorrect speed valve adjustment for the particular airplane or air condition.	Reduce speed valve setting.

Jerky Control

Causes	Remedies
(a) Sticking in follow-up pulleys.	Remove control boxes and check condition of spring and bearing. Relubricate if necessary.
(b) Excess friction in follow-up cable between servo and follow-up pulleys.	Examine follow-up cable system and pulleys and free up.
(c) Sticky balanced oil valve.	Free valve. Clean if necessary. Valve will have to be rebalanced if removed for cleaning.

Lagging Control in One Direction Only

Causes	Remedies
(a) Follow-up pulley not wound sufficiently.	Shorten follow-up cable so that when control is hard over in the direction to wind the spring, the spring will be within ¼ turn of being wound tight.
(b) Dirt in balanced oil valve restricting travel in one direction.	Free valve. Clean if necessary. Rebalance after reassembly.
(c) Oil valve not properly balanced.	Balance oil valve with control units removed. Replace control unit and recheck. See instructions above.
(d) Unbalanced air cut-off in control unit.	Remove control unit and determine if control speed is equal in both directions when same pressure is applied to either side of air relay, which would indicate trouble in the control unit. Check operation with a control unit known to be good. Repair or replace defective control unit.

Lagging Control in Both Directions

Causes	Remedies
(a) Speed control valves closed too much.	Open valves.
(b) Oil pressure too low.	Reset pressure regulator to amount previously known to be satisfactory.
(c) Oil supply choked.	Examine interior of flexible hose, especially suction line to pump. Check oil supply lines and oil filter and clean if necessary.
(d) Vacuum too low to give full travel of air relay and balanced oil valve.	Adjust regulator to 4″ Hg.
(e) Servo relief valve set too low.	Check in accordance with instructions.

Control in One Direction Only

Causes	Remedies
(a) Balanced oil valve restricted by dirt.	Operate manually to check. Free and clean valve if cause of trouble.
(b) Follow-up or piping reversed.	Connect according to control diagram.
(c) Air leak at air pick-off grommet between control unit and mounting bracket.	Install new grommet and check.

CONTROL MOVES TO EXTREME POSITION WHEN GYROPILOT IS TURNED ON. If this takes place, repeat a few times, turning the gyropilot ON with the follow-up index first to one side and then to the other side of the gyro index. If the control always moves the same way, check as explained above, "Control in One Direction Only." If it moves either way, always to take the follow-up index away from the gyro index, check as follows:

(a) Reversed connections between balanced oil valve and servo.	Check with diagram and correct.
(b) Follow-up direction reversed.	Check with diagram and correct.

REVERSED CONTROL. Control moves in wrong direction in response to knob movement (stopping with follow-up index matching gyro index).

This can only be caused by a reversed follow-up *plus* reversed connections between the balanced oil valve and the servo. Check both with diagram and correct.

REVERSED FOLLOW-UP CABLES. A reversed follow-up cable will cause a control to move in the wrong direction to one or the other extreme positions when the gyropilot is turned on. The follow-up pointer will move away from coincidence with the gyro indication instead of toward it. The connections should be checked first at the follow-up pulleys, using the diagram shown in Figure 246, and rechecked in the cockpit as follows:

Right rudder should move the rudder follow-up card to the *left*.

Right aileron should move the aileron follow-up index to the *right*.

Down elevator should move the elevator follow-up index *up*.

REVERSED SERVO OIL LINES. If the connections between a balanced oil valve and a servo cylinder are reversed, opposite control will result, continuing to the end of the control travel. The diagram (Figure 247) should be used to check this portion of the system.

Installation Survey

Airplane Requirements. The requirements which the airplane must meet are few. There must be drives and clearances on the engines for both the oil and vacuum pumps. Although servo units cast en bloc are usually used, individual servos with mechanical by-pass, or individual push-pull type servos may be used, depending upon the control cable arrangement of the particular airplane. When the servo unit is to be in series with the control cables, it is desirable to use the full servo piston stroke. If this is impossible due to the shortness of the control cable travel, it is recommended that a parallel system be installed, with bell cranks, to utilize the full servo stroke. The reason for this is to prevent over-control oscillation which might result if minimum piston movement should produce too much angular deflection of the control surface. The units should be so installed as *to allow access for servicing.*

Selection of Equipment. Determine the requirements in regard to servo unit type and size, oil and vacuum pump types and drives, and drain trap. The proper size follow-up pulleys will be determined from previous experience with gyropilot installations in airplanes of a similar type. It may be necessary to make slight alterations in follow-up pulley sizes after the first test flight in order to secure the best possible gyropilot performance.

Installation Survey. It is suggested that the Aeronautical Service Department of the Sperry Gyroscope Company be contacted and the survey (Figure 249) be submitted to them at the time the installation of a gyropilot is planned. This will insure that advantage is taken of the latest information on detailed improvements in the equipment or method of installation.

Location and Mounting of Units

Mounting Unit. The Mounting Unit should be located in the center of the instrument panel or in front of one of the pilots, as high as possible, in such a position that the faces of

SPERRY GYROSCOPE COMPANY, INC.

INSTALLATION SURVEY

AIRPLANE GYROPILOT, MODEL ....

Date..

AIRPLANE OWNER ....Lic. No. ....

Address ....

AIRPLANE MANUFACTURER ....Type ....

Address ....

POWER PLANT:

No. Engines .... Make ....Model ....

Drives and Clearance Will Be Available for Following Pumps:

	TYPE DRIVE	LOCATION ON ENGINE	PUMP ROTATION	PUMP PART NO.
Oil	....	....	....	....
Air	....	....	....	....

INSTRUMENT PANEL: Drawing of panel and adjacent sections of fuselage desirable

Width ....Depth ....Rear Clearances ....

AIRPLANE DATA: Outline drawing desirable

Length ....Span ....Wing Area ....Gross Wt. ....

Landing Speed .... Cruising Speed ....Top Speed .... Service Ceiling ....

CONTROL DATA:	ELEVATOR Pitch Axis	AILERON Roll Axis	RUDDER Yaw Axis
Airplane Moment of Inertia (Slug Feet Squared)	....	....	....
Airplane Natural Damping Coefficient (Lb. Ft. per Degree per Sec.)	....	....	....
Area (Sq. Ft.)	....	....	....
Aerodynamic Balance or Servo Tab (Per Cent Effect)	....	....	....
Angular Travel Control Surface H. O. - H. O. (Degrees)	....	....	....
Cable Travel H. O. - H. O. (Inches)	....	....	....
Cable Travel - for Surface Movement From 5° on One Side of Neutral to 5° on Opposite Side. (A-2 and A-3 Only) (Inches)			
Hand and Foot Movement H. O. - H. O. (Inches)	....	.... (Dia. and turns of wheel)	
Maximum Manual Forces Required Measured - Estimated (Lbs.)	....	....	
Trimming Tabs?			
Static Balance?			
Distance From Control Surface Axis to Its Center of Pressure (Ft.)			
Distance From C. G. to Control Surface Axis or Center of Pressure (Ft.)			

Form 1680-B Sheet 1

Figure 249. Instal-

PROPOSED LOCATION OF UNITS: PART NO. LOCATION IN AIRPLANE

Dir. Gyro Cont. Unit ________

B. & C. Gyro Control Unit ________

Mounting Unit or Transfer Valve ________ ________

Length of Oil Lines to Servos: Rudder________Ft. Aileron________Ft. Elev. ________Ft.

Height Above Sump or Drain Trap:________Ft.

Length of Air Signal Lines to Instruments (Model A-4 Only):

D. G.. ________Ft. B. & C.________Ft.

Servo Units	PART NO.	MODEL NO.	LOCATION IN AIRPLANE
Rudder		______	________
Aileron	________	________	________
Elevator	________	________	________

Will Servo Cylinders Have to be Rotated From Normal Position? ________

No. of Degrees: Rudder________° Aileron________° Elevator________°

Oil Sump: Part Number________Location in Airplane ________

Location With Respect to Mounting Unit or Transfer Valve________ ___Ft. Above or Below

Location With Respect to Oil Pump________ ___Ft. Above or Below

Length of Suction Line From Sump to Pump.

Oil Pressure Regulator: Part Number__ ·ocation in Airplane________

Adjustment must be accessible

Oil Filter: Part Number________Location in Airplane________

Removable element must be accessible for cleaning

Drain Trap: Part Number________Location in Airplane________

Distance of Tee in Pump Suction Line Above or Below Sump________ ______Ft.

Distance of Tee in Pump Suction Line Above or Below Drain Trap___ ______Ft.

Length of Line From Drain Trap to Tee________Ft.

Length of Line From Sump to Tee________Ft.

	PART NO.	LOCATION IN AIRPLANE
Oil Pressure Gauge		
Vacuum Gauge		
Vacuum Relief Valve	------	
Adjustment must be accessible	------	
On-Off Valve, or Control		

DRAWINGS FURNISHED

TO CUSTOMER TO SPERRY

Customer Rep. ________ Sperry Rep. ________

Signature Signature

Form 1680-B Sheet 2

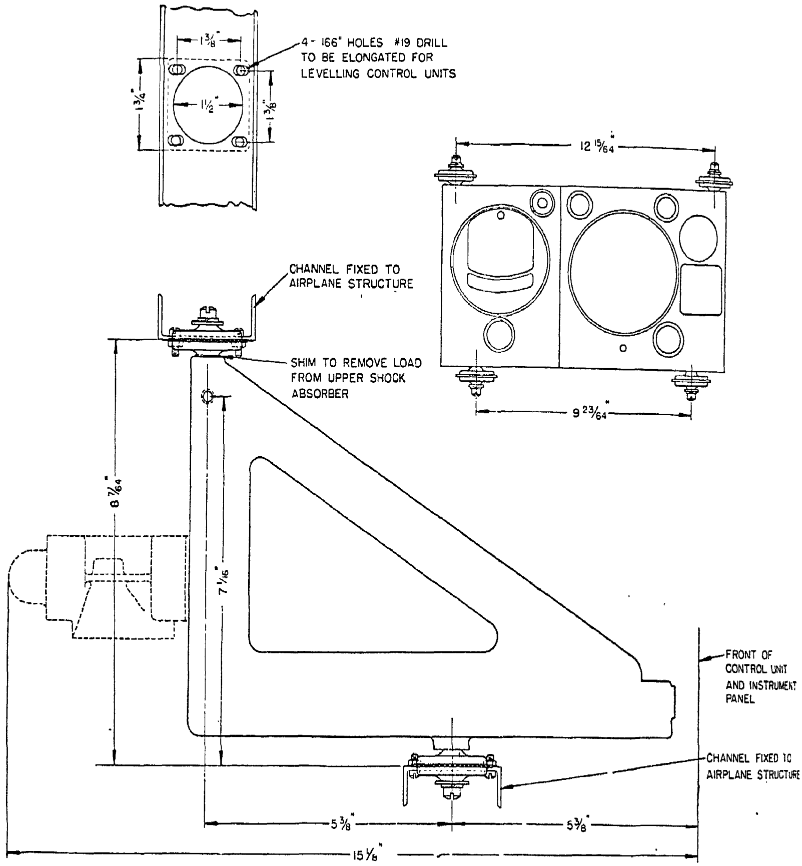


Figure 250. Cross-Section of Mounting Unit Showing how to Attach the Shock-Absorbers

the directional gyro and bank and climb gyro control units will be flush with the instrument panel. There must be a clearance of at least 1/4″ all around. A suggested method of installing the mounting unit is shown in Figure 250.

The shock-absorbers at the bottom of the mounting unit are fastened to a duralumin channel installed across the cockpit behind the instrument panel. The center line of the channel should be 5 3/8″ back of the face of the panel. The shock-absorbers attached to the top of the mounting unit should be fastened to an upper member to keep the unit balanced. The holes in the upper member should be elongated to permit

leveling of the mounting unit. Practically the entire weight of the mounting unit and control units should be carried on the lower shock-absorbers, the upper ones being used principally to balance the unit. It is also important when locating the mounting unit to be sure that the two gyro control units which it carries can be seen easily by the pilot and their various control knobs easily reached. Clearance for removal of the gyro control units is also required. There must be access to the rear of the mounting unit to permit adjustment of the balanced oil valves and removal for cleaning.

The weight of the mounting unit, complete with control units, is approximately 34 lbs. and the center of gravity, laterally, is approximately ¼″ to the left of the center line, looking at the faces of the control units.

An alternative method of attaching the mounting unit, where the entire instrument panel is shock-mounted, is to remove the shock mounts from the mounting unit and attach the mounting unit at these points to brackets fastened to the back of the instrument panel. With this method, it is not necessary to leave the ¼″ cut-out around the control units; leave only enough clearance to permit withdrawal from the panel.

Servo Speed Control Valves. This unit is so arranged that it can be attached to the lower center of the mounting unit which will support it with the face of the speed control valves flush with the instrument panel face. If such a location is not desirable, the speed control valves can be installed in some other position accessible to the pilot. In such a case, the use of the mounting lugs (shown dotted in Figure 266) will permit mounting the speed control valves from the front of the panel.

It is recommended that an oil pressure gauge be used which has a range of zero to 300 lbs., and dimensions to the small AN standard for aircraft instruments. The gauge can be attached to the mounting unit next to the speed control valves, or it may be installed on the main instrument panel convenient to the pilot.

Servo Unit. Cast en Bloc, Double End, Mechanical By-Pass. The Servo unit should be installed in the main control cables in series (Figure 251) when it is possible to design

the airplane control cable installation so that a cable from each of the three controls will pass through the location desired for the servo, spaced the same as the servo piston rods. Where such design is not feasible, a parallel type of installation should be used as shown in Figure 252. Servo rods can only be used in tension with cables. The equipment is not designed for use in compression. For either installation, brackets and structure to which the servo unit is attached shall be sufficiently strong to withstand the design load of any two cables applied simultaneously. (Civil Aeronautics Board regulation.) It is recommended that the servo unit be mounted in a horizontal position as shown in Figure 252 in order to preclude the possibility of air being trapped in the cylinders.

INDIVIDUAL DOUBLE-END SERVOS, MECHANICAL BY-PASS. The installation of this type of servo is similar to the above, except that three different locations will have to be selected, depending upon the cable arrangement. The "On-Off" system will have to be attached to a common control lever unless it is desired to so arrange the system that each of the three servo units can be by-passed individually.

PUSH-PULL TYPE, HYDRAULIC BY-PASS. The general arrangement of this type of installation is shown in Figure 253. Pressure from the oil pump is used to close the spring-loaded by-pass valve in each servo when the "On-Off" valve is in the "ON" position. When this valve is in the "OFF" position, the valve chamber in the servo unit is vented to the sump, and the valve is opened by the action of the spring. Figure 259 shows the valve handle in the "ON" position. When turned 90° counter-clockwise, the valve is "OFF." This three-way valve, for engaging and disengaging the gyropilot, may be installed on the front of the fire wall with a remote control in a location which is convenient to the pilot.

Servo units of the push-pull type should be installed in such a way that no side loads will be exerted on the piston rods. They should also be installed so that both end bearings are in the same plane. They should be mounted so that there is very little angu-

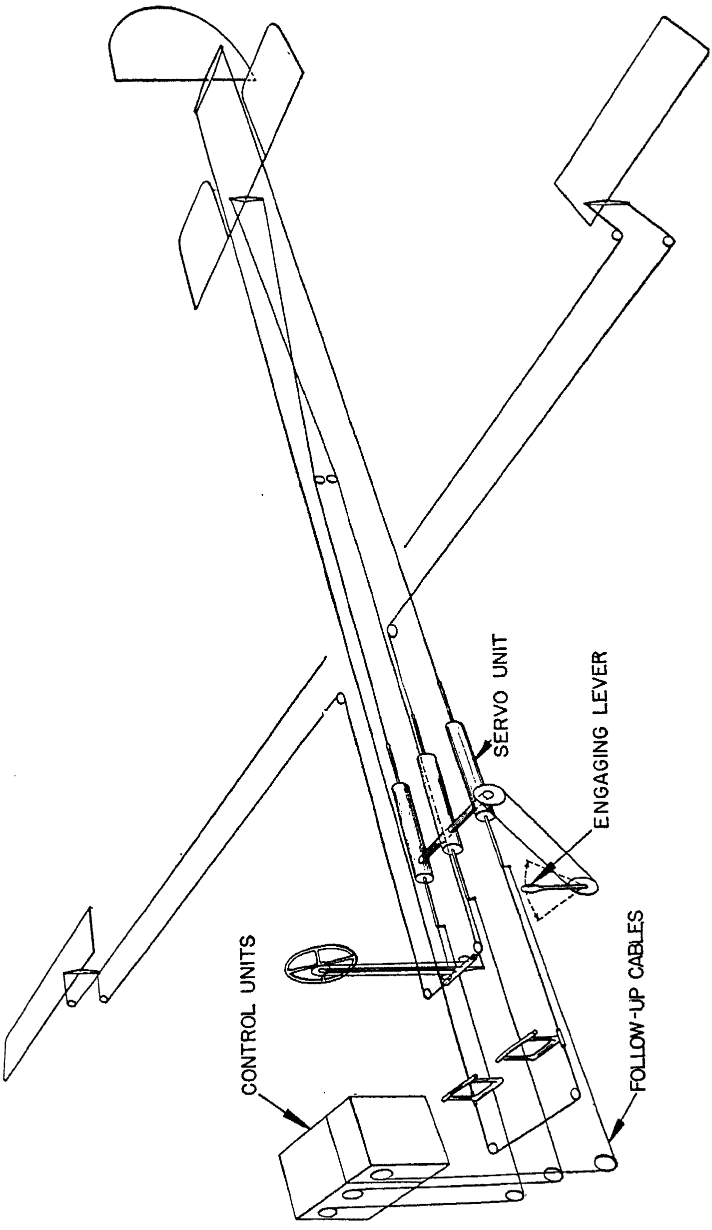


Figure 251. Schematic Drawing Showing Arrangement of Cable Connections with Servo in Main Control System

lar motion in any plane other than that in which the servo is intended to operate. The servos have self-aligning ball bearings at each end, and approximately two degrees of angular motion in more than one plane is permissible.

The servos are to be attached to the airplane structure and control system by inserting ¼″ aircraft bolts through the ball bearings, the bolts to be safetied in accordance with the airplane manufacturer's specifications.

Stops are to be provided in the airplane's control system, set so that the servo unit is not employed as a stop at the end of its stroke. Figure 253 shows a suggested method of attaching the servos to the controls, but any variation of this arrangement can be used, depending on the individual requirements of the airplane.

The servo units are to be mounted preferably so that the six pipe-tapped oil connections are on top. If it is impossible to do this, the servo cylinder may be rotated in either direction by removing the end cap and replacing it in a different position. If necessary, the oil line to the balanced oil valves may be connected to the outlets at the sides of the cylinders instead of the ¼″ outlets at each end of the machined surface on the top of the servo. Each oil line to the balanced oil valve can thus be connected at any one of three outlets on the end of the servo necessary to give correct control movement.

Connections and resulting direction of piston should be proper.

Civil Aeronautics Board Regulations. For servo types listed above, it is necessary that each servo unit's attachment, its supporting structure, its bell crank attaching the piston rod to the control system, and its bell crank supporting structure are capable of withstanding the ultimate load acting through the piston rod. When common supporting structures are used, these structures must be capable of withstanding the ultimate loads from two of the servo piston rods acting simultaneously.

Oil Sump and Pressure Regulator. The sump should be placed below the level of the mounting unit to permit gravity

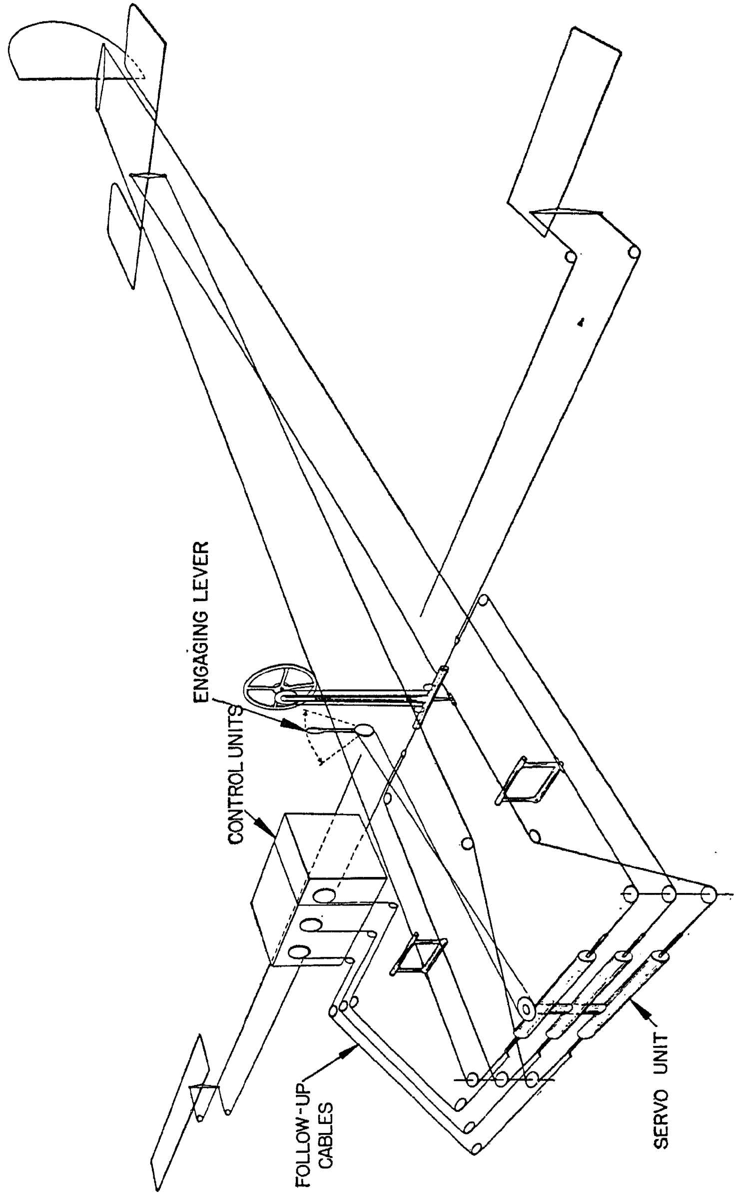


Figure 252. Schematic Drawing Showing Arrangement of Servo Cable Connections Paralleled into Main Control System

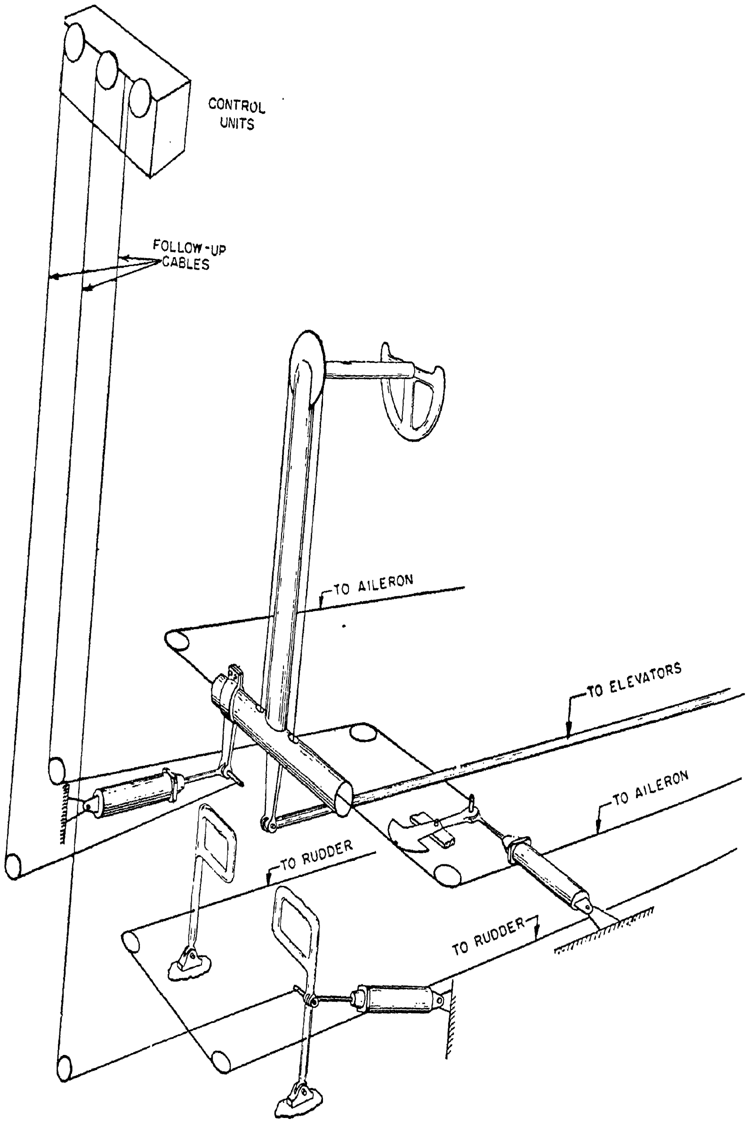


Figure 253. Suggested Method of Attaching Servo Units, Push-Pull Type

drain from the latter. Where it is not possible to carry out this condition, a drain trap must be used to insure return of drainage oil to the hydraulic system. In no case shall the sump be placed more than 5 feet above the drain trap. If the drain oil should have to be lifted more than 5 feet in order to be returned to the sump, then some other means such as an oil drain pump must be used. It is also desirable that the sump be located on a level with or above the oil pump to permit proper priming of the pump, but this condition should not take precedence over the primary consideration, which is to have gravity drainage from the mounting unit to the sump. The sump location should permit observance of the sight gauge and accessibility for filling when the airplane is being serviced. If space is limited, the oil pressure regulator may be removed from the sump and installed in the pressure line between the pump and the filter. To do this, plug the opening in the top of the sump and the bottom outlet on the pressure regulator, and run a line from the outlet on the regulator marked "sump" to a tee at the sump in the return line from the speed valve.

A vent line should be installed at one of the outlets on the top of the sump. On airplanes which are expected to perform acrobatics, the vent line should be carried down as far as the bottom of the sump on either the forward or aft side—preferably the latter. The structure to which the sump is attached should be sufficiently rigid so as not to vibrate excessively.

Oil and Vacuum Pumps. Oil and vacuum pumps are installed on the drives provided for them on the aircraft engines.

Vacuum Relief Valve. Locate and mount the vacuum relief valve (as close to the mounting unit as possible) so that it can be reached easily for adjustment and cleaning of the intake filter screens. If desired, it can be mounted on either end of the mounting unit, where mounting holes are provided, with air intake facing inboard. This allows access for cleaning screen by removing control units.

Oil Filter. Located in the main oil pressure line between the pressure regulatoı and the balanced oil valves, this unit should

be supported rigidly and installed so that the inner element can be easily removed for dismantling and cleaning.

Air Filter. Install this unit as close as possible to the mounting unit. The filter must be accessible for removal of the filter element and clearance must be left to prevent obstruction at the inlet end. Be sure plug is removed from inlet end of filter at time of installation.

Drain Trap. The drain trap when used should be within 1 to 3 feet of the mounting unit, sufficiently below the latter to provide good gravity flow from the drain manifold and not more than 5 feet below the oil sump location. Accessibility, sufficient suction in the oil intake line, and proper support are the only requirements governing the drain trap installation.

Manifold Block. This unit should be mounted at the junction between the flexible oil line connections on the mounting unit and the rigid oil lines to the servo units.

Hookup of Units

Mechanical System. The MAIN CABLES, which are attached to the ends of the servo unit piston rods, should have their pulleys and guides located so that no side loads will be exerted on the servo rods. In laying out the installation, any cylinder can be used for any given control in either direction, the follow-up cables and tubing being connected to the proper places on the mounting unit. The ⅜″–24 threads on the ends of the piston rods take a standard AN clevis. Stops should be provided in the airplane's control system set so that the servo unit is not employed as a stop at the end of its stroke. It is preferable to lay out the control system using the servo unit in series as shown in Figure 251, as it generally reduces the amount of cable and pulley installation required. It may be necessary on some airplanes to use a parallel installation as shown in Figure 252, or a combination of series installation for some control and parallel

for another. The rods of the servo have a tensile strength of 9,675 lbs. Figure 253 shows a suggested method of attaching the push-pull type servo units.

The Follow-up Cables should *in every case* be attached to the servo unit rods. Arrangements should be made so that the follow-up cables and the main cables cannot become twisted. A suggested method of using long bolts held by a slotted guide plate is shown in Figure 254. The follow-up cables should be 1/16″ diameter 7 x 7 flexible preformed cable. Between the cable attachment on the servo and the follow-up pulleys on the

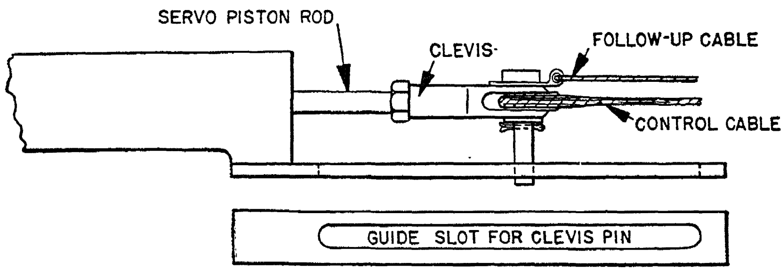
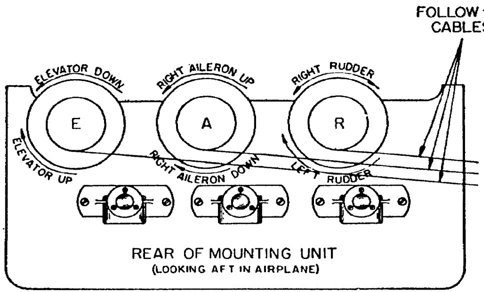
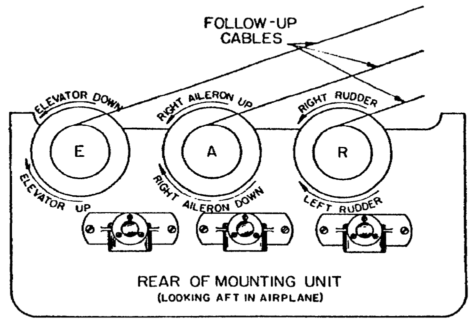


Figure 254. Suggested Method of Attaching Control and Follow-up Cables to Servo Piston Rods to Prevent Twisting

mounting unit, use only ball bearing aircraft pulleys of not less than 2″ diameter. The follow-up cables should be protected by a guard at any place where they may be interfered with by crew, passengers, or material. Follow-up cables should be as short as possible and follow the most direct route from the servo to the mounting unit. It is recommended that these cables never exceed 15 feet in length. It is absolutely necessary to maintain the proper relation between the direction of control surface movement and the direction of rotation of the follow-up pulley. Follow-up pulleys are caused to move in one direction of rotation by the pull of the follow-up cable attached to the servo piston rod and in the other direction by a clock type spiral spring in the follow-up pulley, which keeps tension on the follow-up cable when the cable is moving toward the pulley. Follow-up pulleys can be furnished with the spring drive for



SHOWING LEFT HAND PULLEYS



SHOWING RIGHT HAND PULLEYS

CABLES MAY BE INSTALLED TO PULL FOLLOW-UP CLOCKWISE OR COUNTERCLOCKWISE DEPENDING ON HOOK-UP TO SERVO AND HOOK-UP OF SERVO TO CONTROLS. IN ALL CASES, HOWEVER, THE RELATION BETWEEN CONTROL SURFACE MOVEMENT AND DIRECTION OF FOLLOW-UP PULLEY ROTATION MUST BE AS ABOVE.

LEFT HAND FOLLOW-UP PULLEYS

NUMBER	SIZE-DIAMETER
150544	1"
150545	1 1/8"
150546	1 1/4"
150547	1 3/8"
150548	1 1/2"
150549	1 5/8"
150550	1 3/4"
150551	2"
150552	2 1/4"
150553	2 1/2"
150554	2 3/4"

NOTE

ANY COMBINATION OF LEFT OR RIGHT HAND PULLEYS MAY BE USED AS REQUIRED TO SIMPLIFY FOLLOW-UP CABLE INSTALLATION.

RIGHT HAND FOLLOW-UP PULLEYS

NUMBER	SIZE-DIAMETER
151391	1"
151392	1 1/8"
151393	1 1/4"
151394	1 3/8"
151395	1 1/2"
151396	1 5/8"
151397	1 3/4"
151398	2"
151399	2 1/4"
151400	2 1/2"
151401	2 3/4"

Figure 255. Diagrammatic Drawing Showing Follow-Up Pulley Arrangements and Sizes

either direction of rotation. For double end type servos cable attachment at the servo should be at the rod end providing the simplest cable run to the follow-up pulleys. For push-pull type servos, attach the follow-up cables at the point where the piston rod is connected to the bell crank or control column. With this type, no guide slot is necessary to prevent the cables from twisting. Pulleys should be selected to meet the following conditions, looking aft in the airplane at the follow-up pulleys on the mounting unit:

RUDDER—Right rudder movement should produce counter-clockwise rotation.

AILERON—Right aileron (right aileron up, left down) movement should produce counter-clockwise rotation.

ELEVATOR—Down elevator movement should produce counter-clockwise rotation.

If the installation is the first in a given type of airplane approximately 3″ excess cable should be left beyond the point of attachment of the pulley. This will permit changing pulley sizes after experimental flights until the proper follow-up ratios have been determined, depending upon airplane performance.

Caution: Be sure extra cable is arranged so that it cannot interfere with follow-up pulley action. Cut off extra length when tests have been completed.

A suggested method for attachment is to mark the cable first at the place where it passes through the slot (with follow-up pulley wound up within ¼ turn of its fully wound position). Then slide a small washer over the end of the cable, cut the cable close to the washer, bend the strands over the surface of the washer, and solder them securely.

After the cable has been attached, move the control slowly to the other extreme position. Check for smooth movement and to see that there is sufficient spring tension to hold the cable taut. Figure 255 shows the follow-up cable and pulley arrangements possible and designates which pulleys can be used for either direction of rotation.

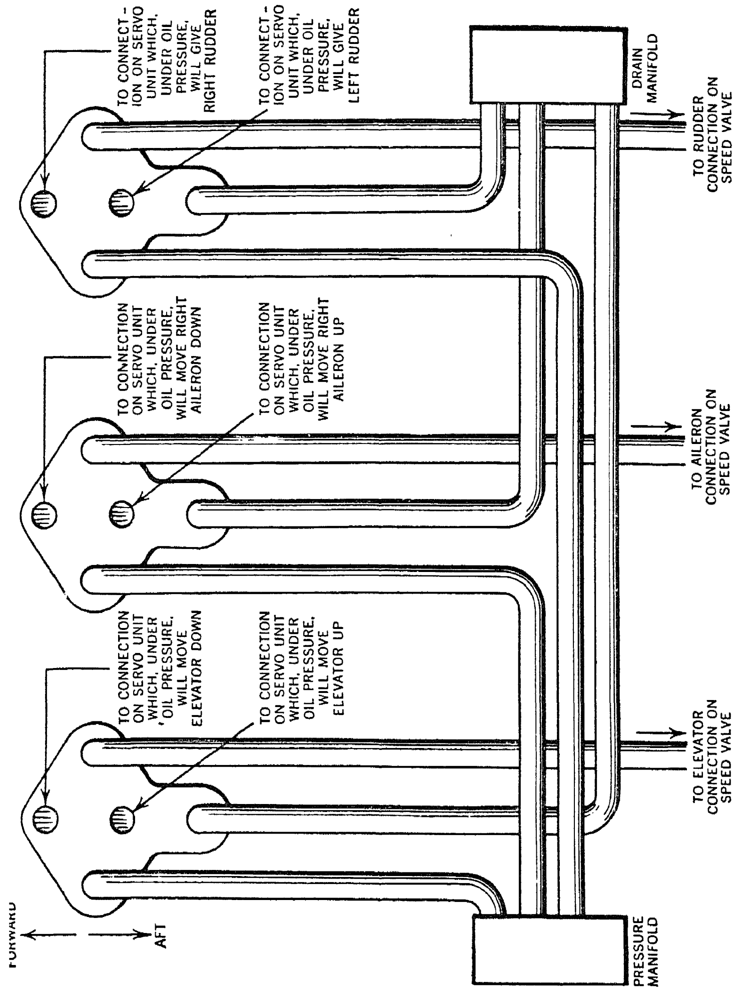


Figure 256. Diagrammatic Drawing Showing Method of Making Oil Line Connections to Balanced Oil Valves

The On-Off Cable should be attached to a lever convenient to the pilots and to the On-Off pulley on the servo unit. Figure 263 shows the direction of rotation at the servo for On and Off. 1/16″–7 x 7 preformed flexible cable should be used. The installation should be made in such a manner as to preclude any possibility of failure of the On-Off system. Where a direct short run is possible from the servo to the hand lever, the pulley on the servo may be replaced by a lever and a direct push-pull rod may be used. For push-pull servos which are controlled hydraulically, the direction of the valve handle for "Off" and "On" is indicated in Figure 259.

Hydraulic System. The reliability of the gyropilot installation will depend to a large extent on the quality of the hydraulic installation as regards layout, material, and workmanship.

Material. 52–SO aluminum alloy tubing should be used. Standard flare type fittings are recommended of forged dural wherever possible, cast aluminum alloy when the forged type is not available. A good grade of anti-seize or thread lubricant for aluminum or dural should be used. Flexible hose should be used at points of vibration and at flexible mountings. Do not use copper tubing, gasket cement, shellac or dope, or rubber tubing.

Workmanship. *Chips, filings, or dirt must not be permitted to enter the piping of either the hydraulic system or the air system.*

Fit each section of piping separately, cut ends off square and remove all burrs. Use standard flaring tools to obtain a proper fit with the tapered portion of the fittings. *Too much vigilance cannot be exercised to see that the tubing is properly flared.*

Important: Before making any connections of any section of the piping, wash out each piece of piping separately by pumping gasoline, kerosene, or carbon tetrachloride through it, and blow out with compressed air.

Care must be exercised in applying the thread lubricant to prevent this material from getting into the system. Coat fitting evenly all around and wipe off excess before assembling.

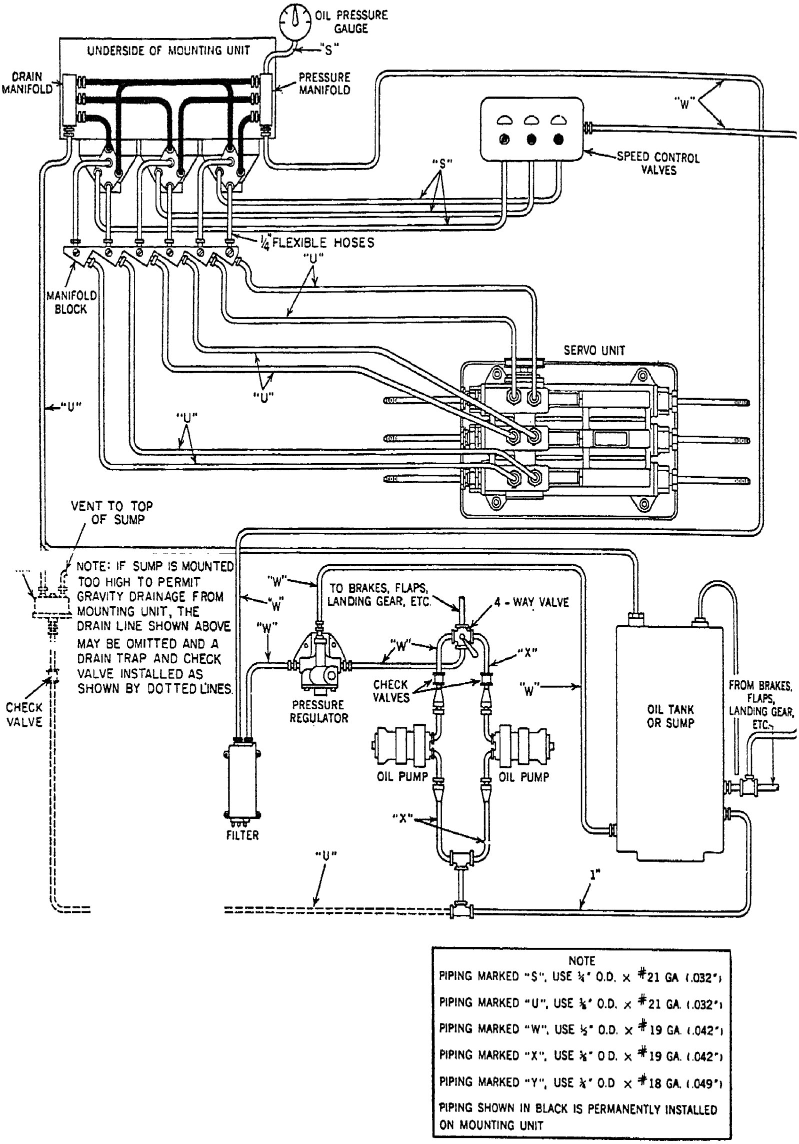
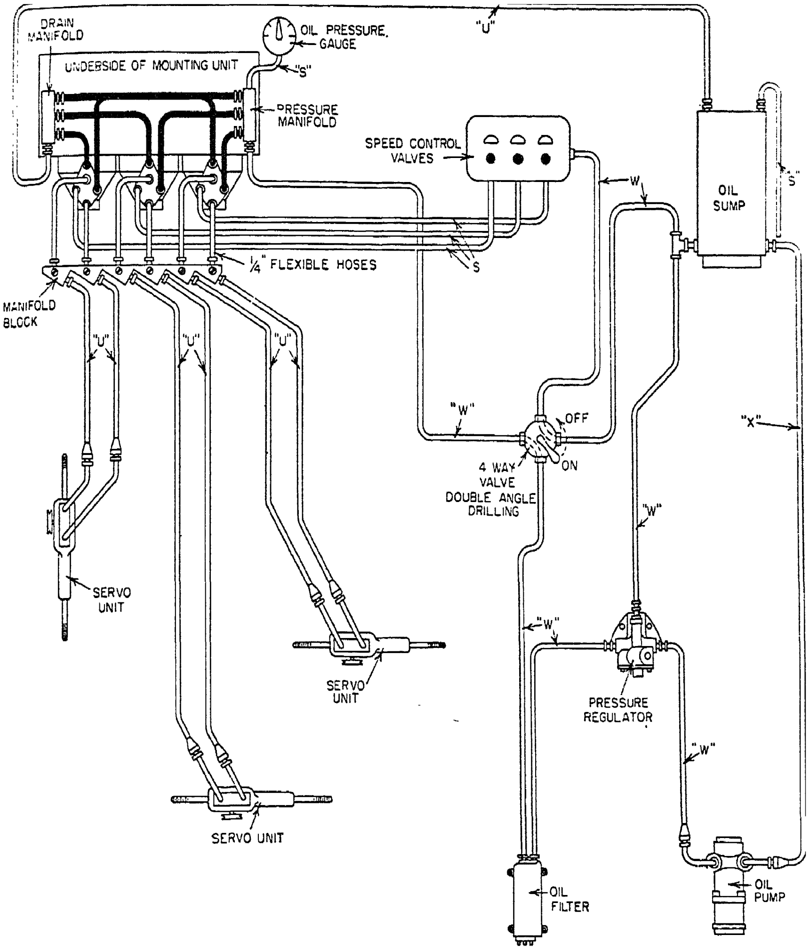


Figure 257. Diagrammatic Drawing of Hydraulic System with Sump Common to both Gyro pilot and Airplane's Auxiliary Hydraulic Equipment



NOTE

PIPING MARKED "S" USE ¼" O.D. #21 GA. (.032")

PIPING MARKED "U" USE ⅜" O.D. #21 GA. (.032")

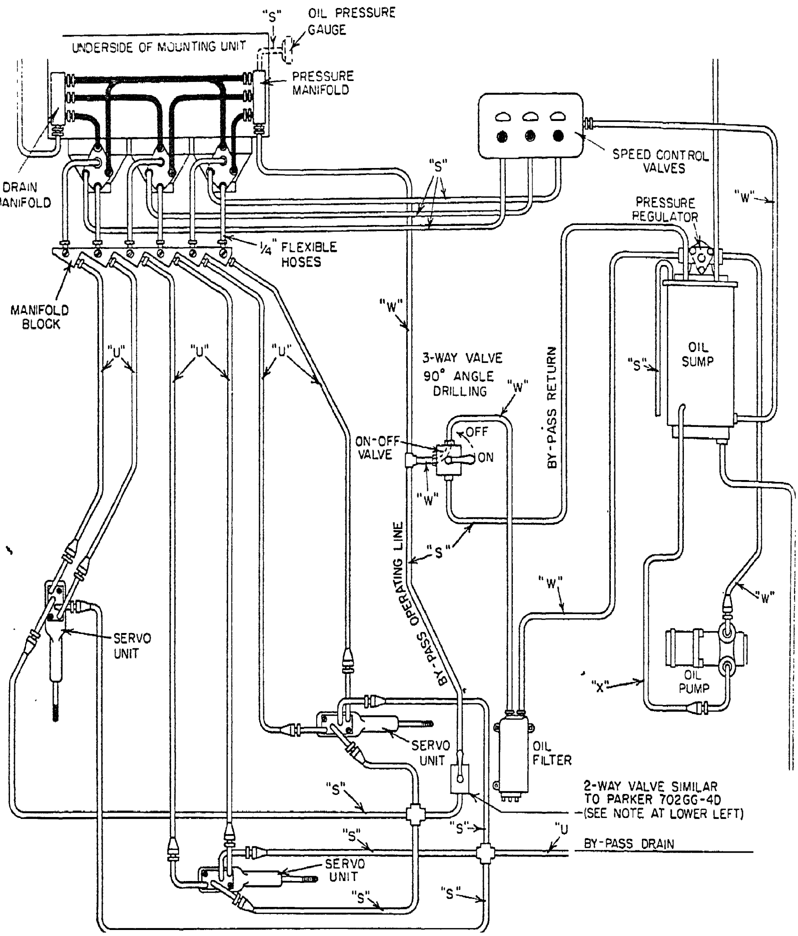
PIPING MARKED "W" USE ½" O.D. #19 GA (.042")

PIPING MARKED "X" USE ⅝" O.D. #19 GA (.042")

PIPING MARKED "Y" USE ¾" O.D. #18 GA (.049")

PIPING SHOWN IN BLACK IS PERMANENTLY INSTALLED ON MOUNTING UNIT.

Figure 258. Diagrammatic Drawing of Hydraulic System with Individual, Double-End Servos. Pressure Regulator Shown Removed from Sump and Installed Elsewhere in Pressure Line



NOTE: 2-WAY VALVE

THE 2-WAY VALVE SHOWN IN THE BY-PASS OPERATING LINE SHOULD BE SAFETIED IN THE OPEN POSITION AS SHOWN EXCEPT WHEN WORKING AIR OUT OF THE GYRO-PILOT HYDRAULIC SYSTEM. TO AVOID CONFUSION, KEEP THIS VALVE WELL AWAY FROM THE 3-WAY ON-OFF VALVE. THE 2-WAY VALVE NEED BE ACCESSIBLE ONLY WHEN THE PLANE IS ON THE GROUND.

NOTE

PIPING MARKED "S", USE 1/4" O.D X #21 GA.(.032")

PIPING MARKED "U", USE 3/8" OD. X #21 GA. (.032")

PIPING MARKED "W", USE 1/2" O.D.X #19 GA. (.042")

PIPING MARKED "X", USE 5/8" O.D.X #19 GA (.042")

PIPING MARKED "Y", USE 3/4" O.D. X #18 GA. (.049")

PIPING SHOWN IN BLACK IS PERMANENTLY INSTALLED ON MOUNTING UNIT.

Figure 259. Diagrammatic Drawing of Hydraulic System with Push-Pull, Hydraulic By-Pass Type Servos

When making connections, tighten nuts carefully. Excessive tightening will damage the flared end of the tubing and cause leaks.

Be sure that all joints are tight and that all tubing is secured to eliminate vibration. Be sure that tubing cannot chafe against any structure to cause a leak at a later date. Avoid right-angle bends as much as possible, as these restrict the flow of air or oil within the tubing.

LAYOUT. Figures 257, 258, and 259 show the basic hydraulic layouts. Figure 257 shows a hydraulic system with a sump which is common to both the gyropilot and to the airplane's auxiliary hydraulic equipment. Servo units cast en bloc are shown in this drawing. Figure 258 shows the use of a single oil pump, and individual, double-end servo units. The pressure regulator is shown removed from the sump and installed elsewhere in the pressure line. A four-way reversing valve is also shown in this illustration, located in the pressure line between the oil filter and the pressure manifold on the mounting unit. With the handle of this valve in its "normal" position, oil is permitted to flow to the mounting unit for the operation of the gyropilot. With the handle turned "OFF," the oil is by-passed back to the sump. Though not supplied with the equipment, this valve is recommended, as it will prevent damage to the pump in case of a leak anywhere in the system beyond the valve, and will make it possible to unload the pump when the gyropilot is not being used. The valve should be placed, preferably, as close to the filter as possible, in such a location that it is accessible to the pilot, either directly or by a remote control. Figure 259 shows the use of push-pull, hydraulic by-pass type servo units. In this illustration the pressure regulator is shown as an integral part of the sump. If because of space requirements it should be necessary to mount the pressure regulator elsewhere, refer to Figure 258 and see instructions under "Oil Sump and Pressure Regulator."

The arrangement in detail of the complete equipment as usually supplied, i.e., with servo units cast en bloc, may be obtained from the Sperry Company.

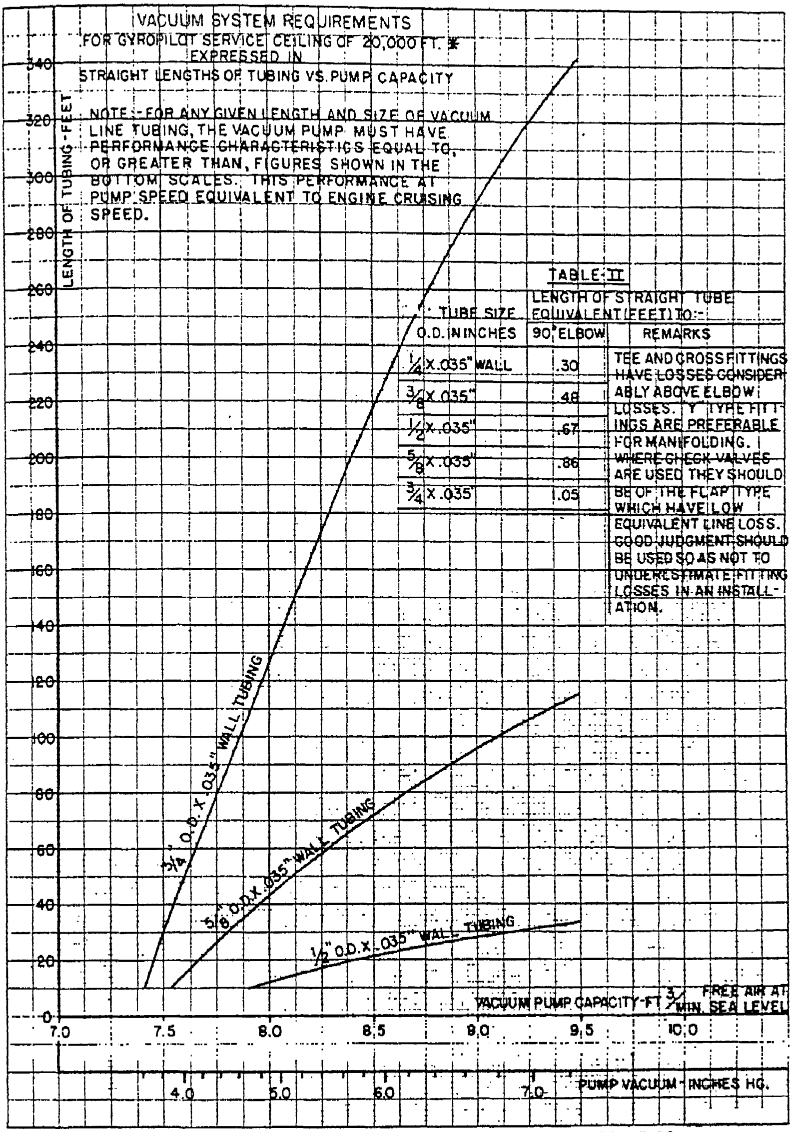
Air System. The range of engine speeds and altitudes through which the gyropilot will operate will depend entirely on the execution of the air system installation. The vacuum pump pulls air from the gyropilot in order to maintain a reduced pressure (suction) in the equipment. The suction causes outside air to flow into the equipment through the air filter to operate the gyros, the air pick-offs, and the air relays. A suction of 3.5″ to 5.0″ of mercury is required to produce satisfactory operation of the equipment. Pumps recommended by Sperry will maintain this suction at 1,000 to 1,200 engine r.p.m. up to 5,000 feet barometric altitude, and at engine cruising r.p.m. at the service ceiling of the airplane. To obtain these results, however, it is absolutely necessary that the drop in the system between the gyropilot and the vacuum pump be such as to require a suction of not more than 7″ of mercury at the vacuum pump in order to maintain a suction of 4″ Hg in the gyropilot at sea level. The curve chart of Figure 260 shows the maximum straight lengths without fittings of various sizes of tubing which can be used and still maintain the conditions mentioned above. Table II lists the drop produced by various types of fittings, expressed in terms of length of tube of the same nominal size which would produce an equivalent drop. The vacuum system is shown diagrammatically in Figure 261. A few simple rules to follow in planning the air system are listed:

Avoid the use of 90° elbows. They cause a large vacuum drop and may force you to use a larger size tubing than would otherwise be necessary. Use straight unions wherever joints are necessary.

Keep the system as simple as possible, especially where there is a duplication of equipment and more than one pump is used. As the result of considerable experience, the Sperry Company is in a position to recommend desirable layouts for various combinations of pumps and equipments.

If any doubt exists, use the next larger size of tubing and fittings. It will call for less load on the pump and will allow more reserve for altitude operation.

Fasten tubing securely with clips or brackets, avoiding the use of friction tape.



* FOR SERVICE CEILING OF OVER 20,000 FT. CONSULT THE SPERRY GYROSCOPE CO.

Figure 260. Vacuum System Requirements

NOTE

PIPING MARKED "U" USE 1/8" O D x NO 21 GA (.032")
PIPING MARKED "W" USE [illegible]" O D x NO 19 GA. (.042")
PIPING MARKED "X" USE [illegible]" O D x NO 19 GA. (.042")
PIPING MARKED "Y" USE [illegible]" O D x NO 18 GA (.049")

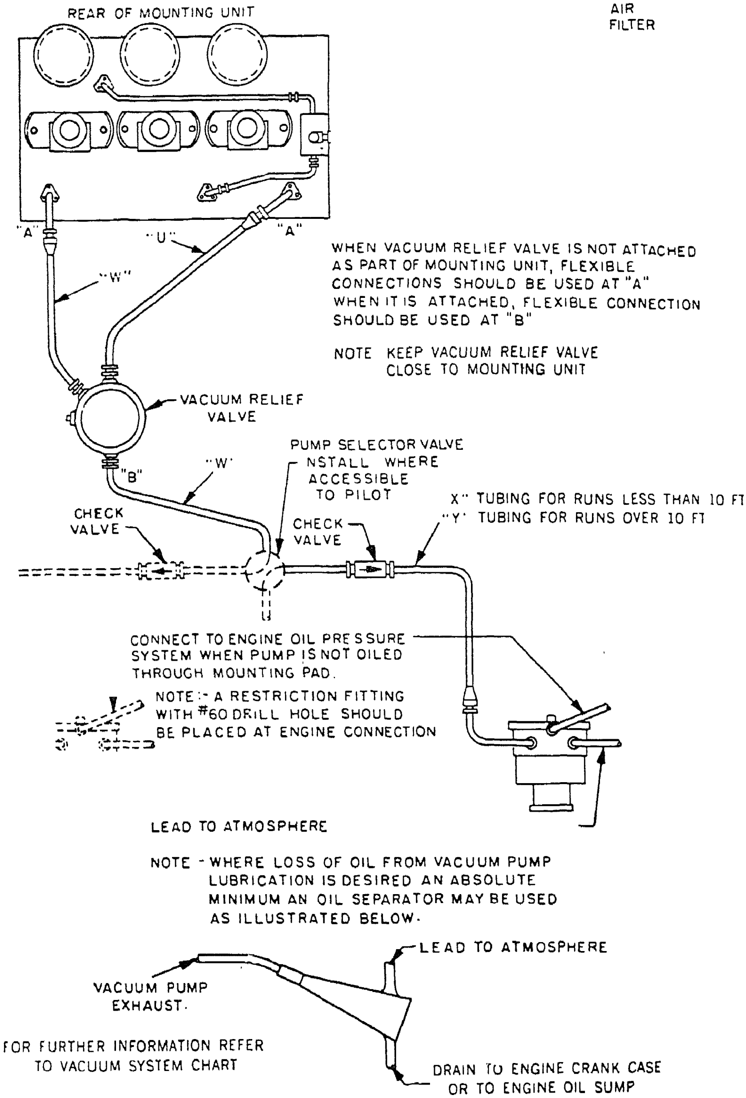


Figure 261. Diagrammatic Drawing of the Vacuum System

Use only flap type check valves. Spring loaded or ball type valves cause a high drop and overload the pumps. Locate the check valve as far from the pump as possible to provide a sufficient volume in which air may be compressed, in the event that an engine kicks and runs backward a few turns. A check valve must be used to prevent damage to the gyropilot due to reverse running or oil discharge from a broken vacuum pump.

Electrical System. The dials of the gyropilot control units are illuminated by 3-volt miniature lamps, one for the directional gyro control unit and one for the bank and climb. The wires for these lamps are self-contained in the instrument cases. Connect to the compass lighting circuit, using radio, shielded cable. Remove the two lighting circuit cones at the back of the mounting unit, pass the two leads through the cone, and attach them to the terminal screws provided. Replace the cone and screw the ferruled nut on the end of the cable to the cone. If necessary, insert a resistor to reduce the supply to 3 volts. (12 volts to 3 volts requires a 60-ohm resistor. 24 volts to 3 volts requires a 120-ohm resistor.) Outline drawings of the principal units and accessories are shown in Figures 262 to 272, inclusive.

Installation Inspection

Upon completion of the installation or as the various phases of it are completed, a careful check and inspection should be made prior to running ground and flight tests.

Mechanical System. THE MAIN CONTROL SYSTEM of the airplane should be thoroughly checked out for freedom of operation and correct direction of operation. All connections should be checked to see that they are properly safetied. Observe the servo piston rods at this time to see that they do not spring or bend due to misalignment of pulleys which lead cable to the servo. Check to see that control system stops are so placed as to prevent use of the servo as a stop. It is not necessary that the servo pistons be centered when the control surfaces are, as long as the ship is rigged so that the surfaces have full angular movement without the servo pistons acting as stops.

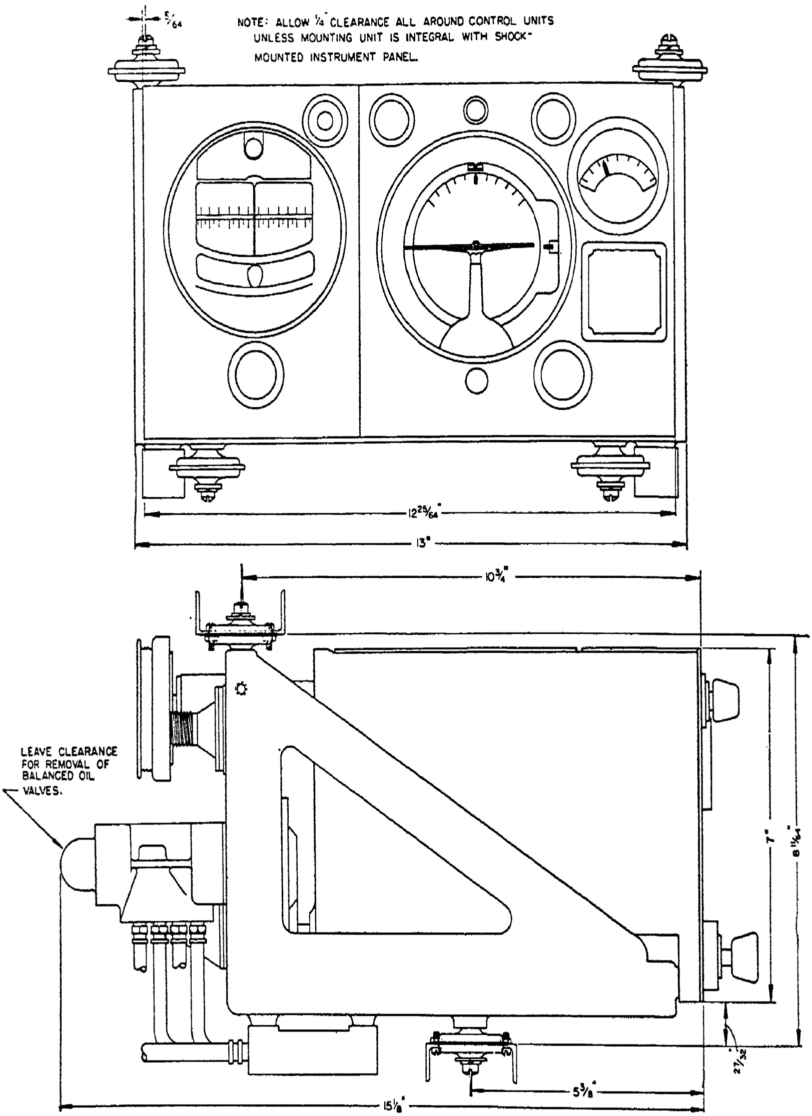
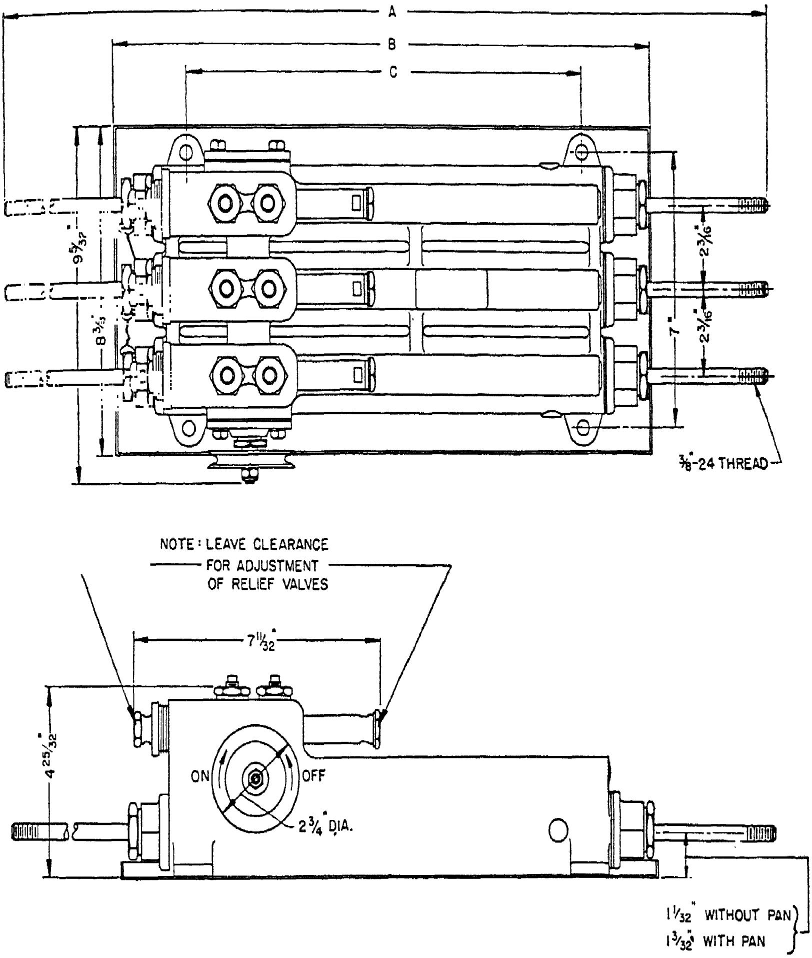


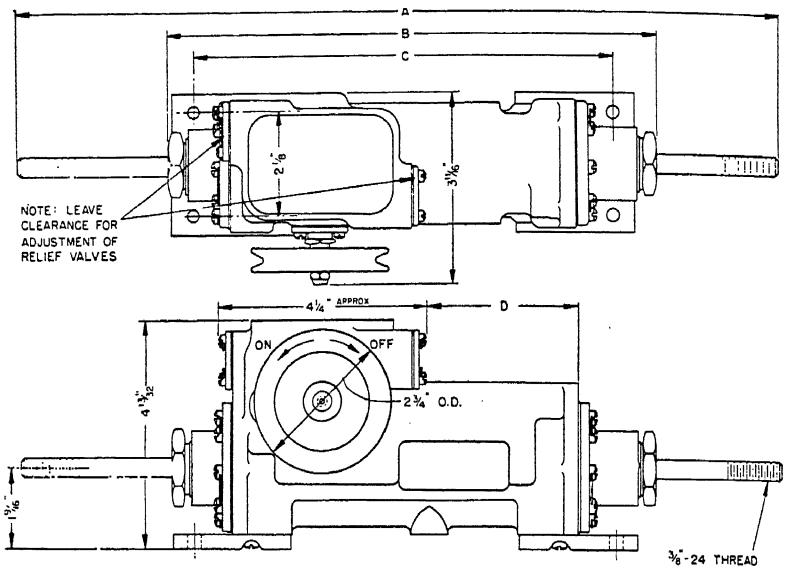
Figure 262. Principal Dimensions of the Control Units in the Mounting Unit



STROKE	A	B	C	WEIGHTS
6 INCH	19 3/4"	11 7/8"	7 5/16"	11 LBS. 13 OZ.
8 INCH	23 3/4"	13 7/8"	9 5/16"	12 LBS. 3 OZ.
11 INCH	29 3/4"	16 7/8"	12 5/16"	14 LBS. 6 OZ.

Figure 263. Principal Dimensions of the Servo Unit, Cast En Bloc Type

THE ON-OFF SYSTEM should be checked to see that the hand lever produces a full 90° throw at the servo and to see that the connections are not reversed. With the lever at OFF, the controls should move freely from one extreme to the other. With

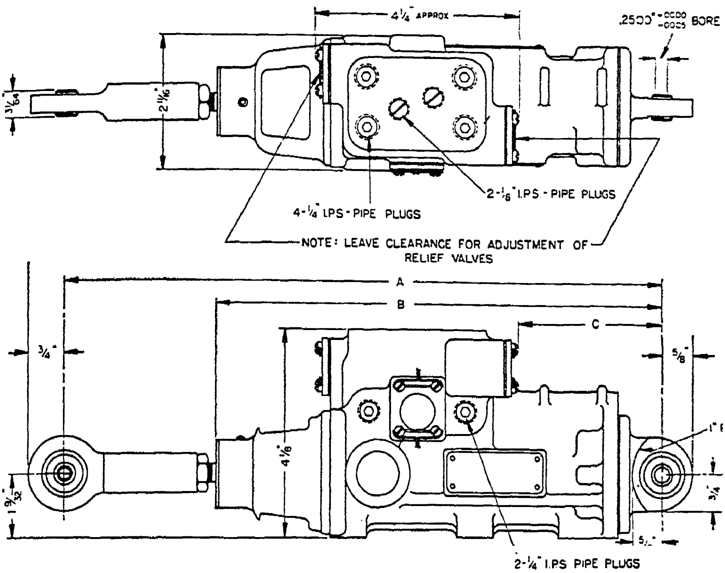


STROKE	A	B	C	D	WEIGHTS
4 INCH	15 7/8"	9 3/4"	8 13/32"	3"	5¼ LBS. APPROX
6 INCH	19 7/8"	11 3/4"	10 13/32"	5"	5¾ LBS. APPROX
8 INCH	23 7/8"	13 3/4"	12 13/32"	7"	6¼ LBS. APPROX
11 INCH	29 7/8"	16 3/4"	15 13/32"	10"	7 LBS. APPROX
15 INCH	37 7/8"	20 3/4"	19 13/32"	14"	8 LBS. APPROX

Figure 264. Principal Dimensions of the Servo Unit, Individual, Mechanical By-Pass Type

the lever ON, compression of air in the servo should be felt as the controls are moved back and forth. Later, when the air is replaced by oil (during the first running of engines), it will not be possible to move the controls manually with the gyropilot on, except by overpowering, which opens the servo relief valves.

During the inspection the pressure for overpowering of the gyropilot should be about twice that ordinarily exerted on the controls. This is a precautionary feature enabling the pilot to "take over" control at any time.



STROKE	A	B	C	WEIGHTS
4 INCH	12¼" MIN / 16¼" MAX	9¼"	3" APPROX	4¼ LBS APPROX
6 INCH	14¼" MIN / 20¼" MAX	11¼"	5" APPROX	4¾ LBS. APPROX

Figure 265. Principal Dimensions of the Servo Unit, Push-Pull, Hydraulic By-Pass Type

The Follow-up System should be checked as follows:

(a) With gyro control units in place and follow-up indices and controls approximately centered, the following relations should hold:

Right rudder application should cause rudder follow-up card to move to the *left*.

Right aileron application should cause aileron follow-up index to move to the *right*.

Down elevator application should cause elevator follow-up index to move *up*.

The follow-up cables should rest in the exact center of the follow-up pulleys to prevent wearing of pulleys and possible binding. The pulleys should be properly aligned in their brackets to permit free movements.

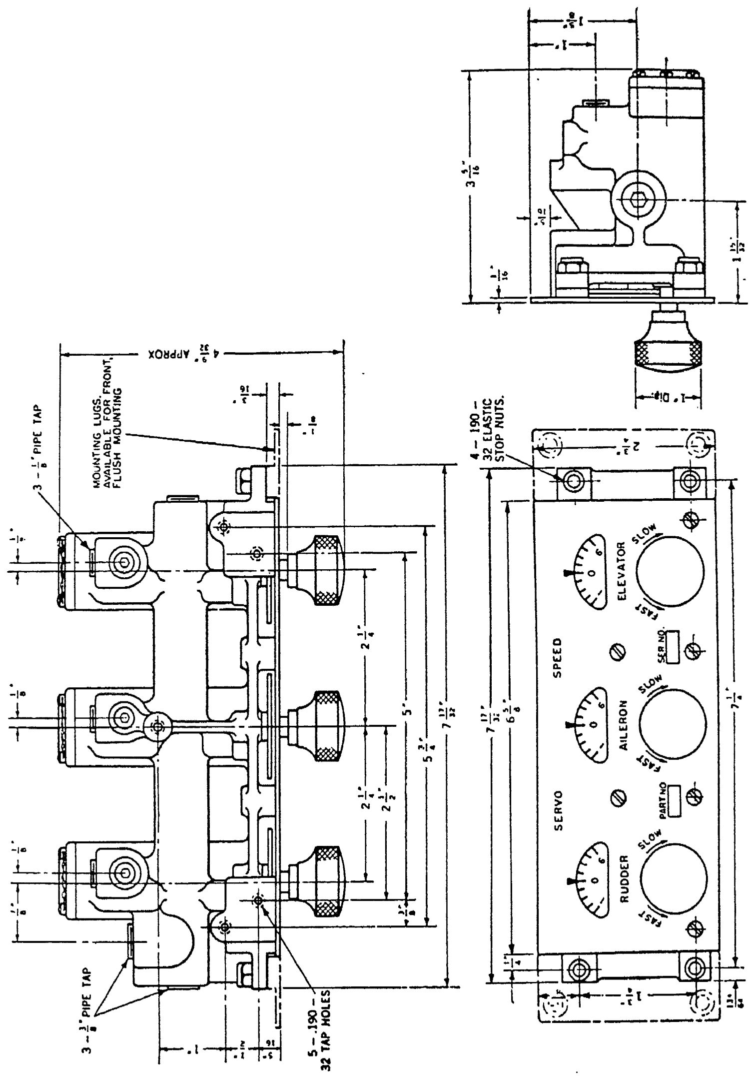


Figure 266. Principal Dimensions of the Speed Control Valves

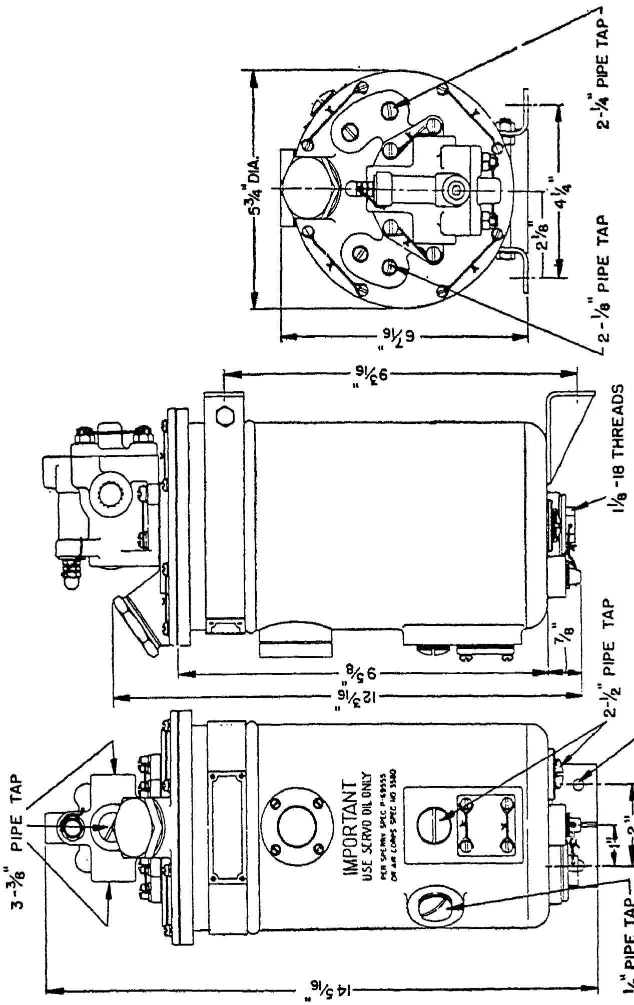


Figure 267. Principal Dimensions of the Oil Sump and Pressure Regulator

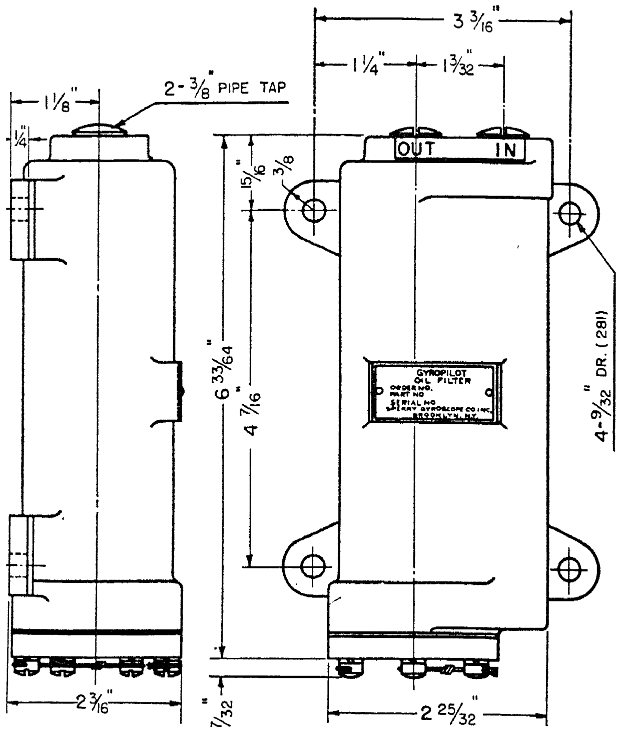


Figure 268. Principal Dimensions of Oil Filter

If any of these motions are reversed, the relation between control movement and follow-up pulley rotation should be rechecked in accordance with the diagram (Figure 255).

(b) Check to be sure that follow-up index motion is smooth as the controls are moved and to see that there is no lag. Should there be any lag or jerky movement of the follow-up, the system should be carefully gone over to eliminate the cause.

(c) Check to see that all connections are properly safetied and that pulleys and cables are properly guarded, so that no chafing of cables can take place.

(d) Be sure that there is tension in the follow-up cables when controls are at the extreme position feeding follow-up cable to the follow-up pulleys. Be sure that the pulley spring is not wound tight at the other extreme. It should be possible to move the pulley about ¼ turn at this position.

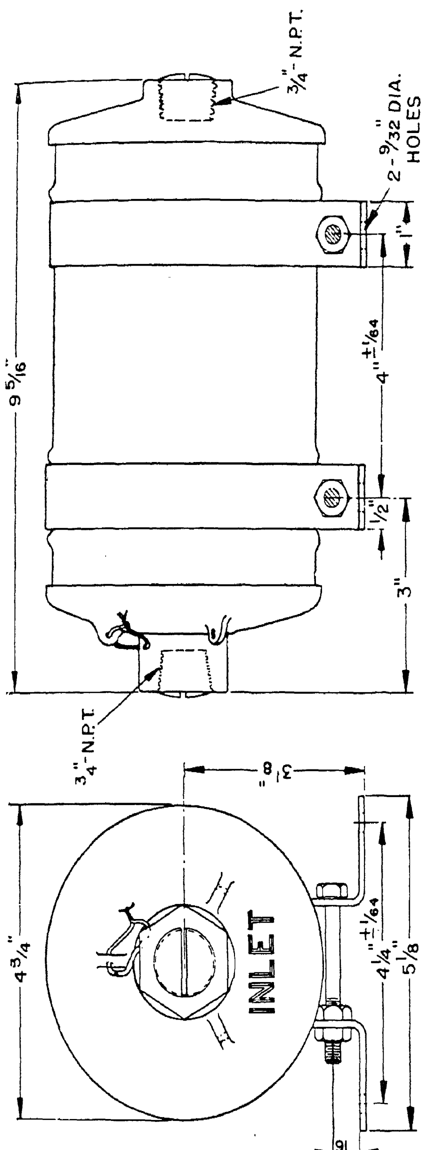


Figure 269. Principal Dimensions of Air Filter

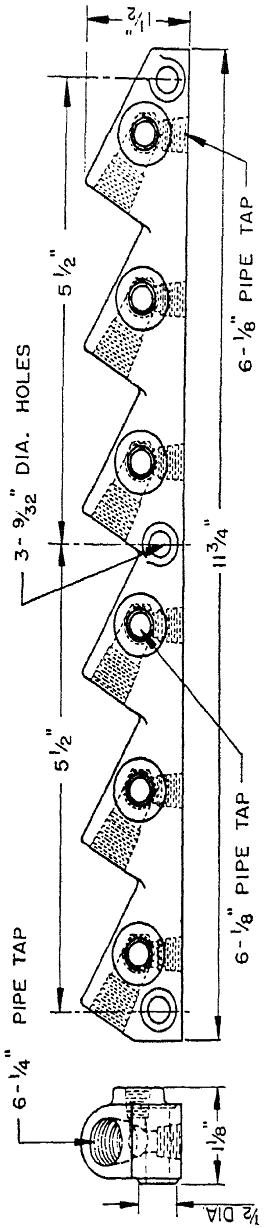


Figure 270. Principal Dimensions of Manifold Block

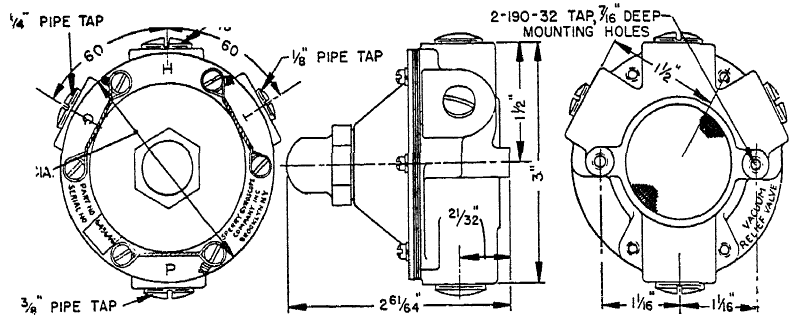


Figure 271. Principal Dimensions of the Vacuum Relief Valve

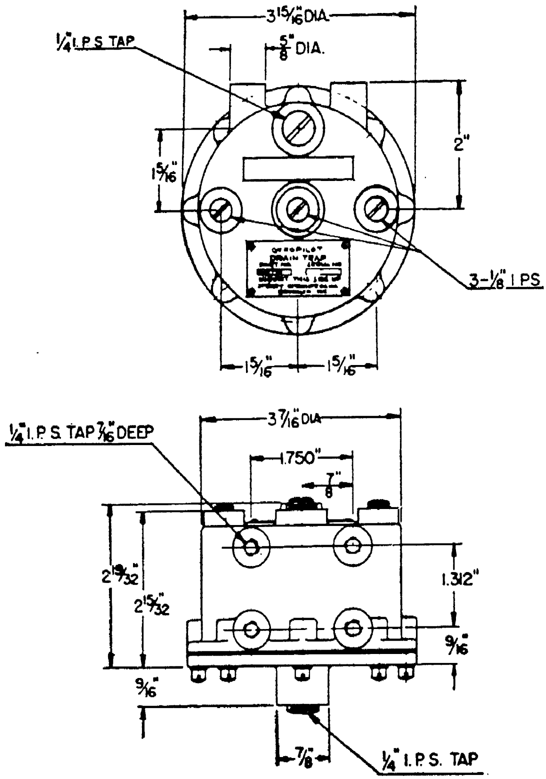


Figure 272. Principal Dimensions of Drain Trap

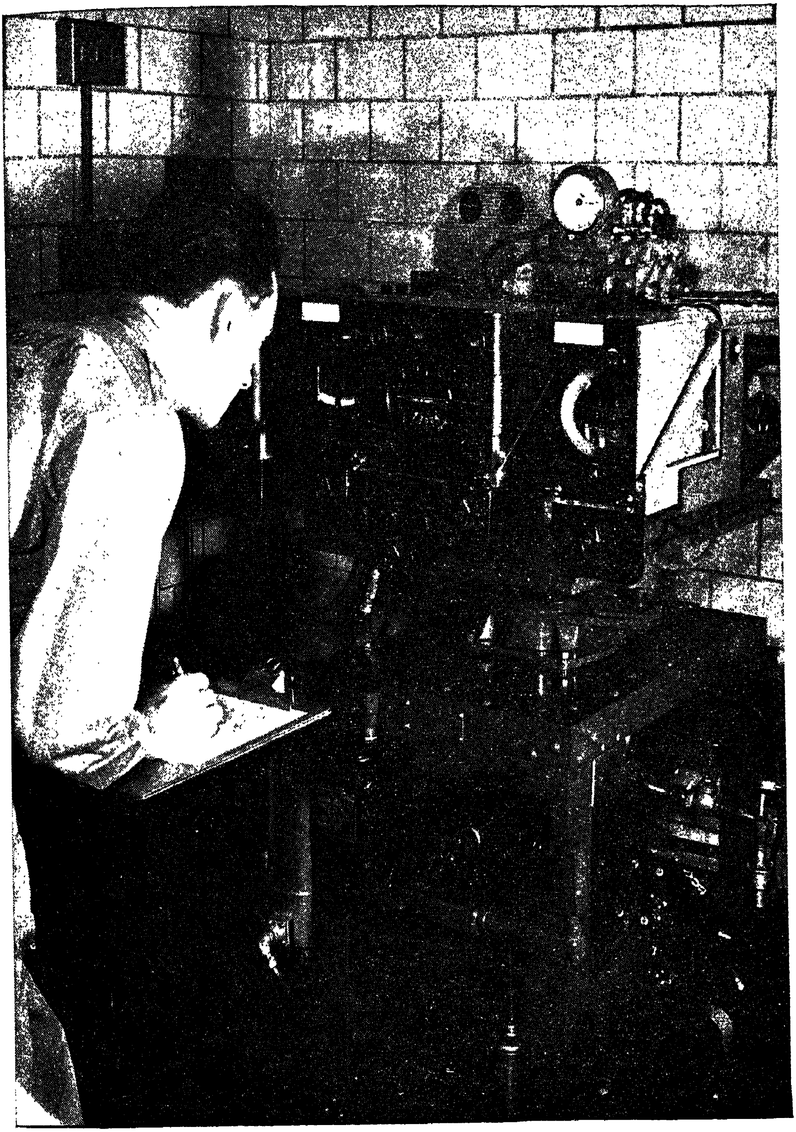


Figure 273. Scorsby Unit for Testing Automatic Pilot
(American Airlines, Inc.)
After complete overhaul and prior to installation on the airplane, the Sperry Automatic Pilot is given a ground check which simulates flying conditions, on the Sperry Scorsby testing unit.

(e) Be sure that the springs in the follow-up pulleys are not dry. A dry spring will rust and bind instead of giving a smooth motion. A few drops of heavy engine oil will suffice.

Hydraulic and Vacuum System. All piping should be traced out to see that it is connected according to the diagrams in Figures 257, 258, and 259 or in accordance with manufacturer's diagrams based on the above-mentioned figures. It is very important to catch any reversed connections at this time so that equipment will not be damaged later when engines are run. Check to see that all joints are tight and all tubing is secure and protected from vibration. Be certain that tubing cannot chafe against any structure to cause a serious leak at a later date.

Electrical System. Wiring should be checked out with a buzzer to detect shorts or grounds and to see that circuits are complete.

CHAPTER 27

PIONEER DIRECT CURRENT AUTOSYN POSITION INDICATOR

THE PIONEER WHEEL AND FLAP POSITION INDICATOR provides the pilot with a definite knowledge of the following functions:

(a) Position of each one of the retractable wheels (or pontoons).
(b) Action of all locks used to maintain these retractable components in position.
(c) Position of the flaps.

All of these functions are extremely important for the safe operation of any airplane. With this instrument, the pilot can at a glance, and without any mental effort or interpolation of a dial, determine if the flaps and retractable landing gear are firmly locked in place. Special dial arrangements are available for ships which retract only two wheels, and for ships which do not have mechanical locks for retaining the wheels in the up position.

As a safety factor, a definite power on and off indicator is provided. This permits the pilot to depend on the indications of this instrument at all times and absolutely prevents his reading the instrument at a time when the power is turned off.

The instrument operates from a direct current power supply and is basically a DC Autosyn. The transmitter and indicator are synchronous and the indications are independent of line voltage or length of leads between transmitter and indicator. The wheel lock indicator uses the standard wheel lock switches.

The dial layout has been maintained to the utmost simplicity, and yet the pilot can, at a glance, get all the information he needs about his landing gear and flaps.

Description

The dial layout of this instrument is such that all the components of the airplane that it covers are represented by small flags appropriately painted. In the upper part of the dial is a simulation of the outline of a twin-engined airplane. Under the center of the fuselage and under each nacelle, small flags move up and down. Each of these flags is luminously painted to represent a wheel.

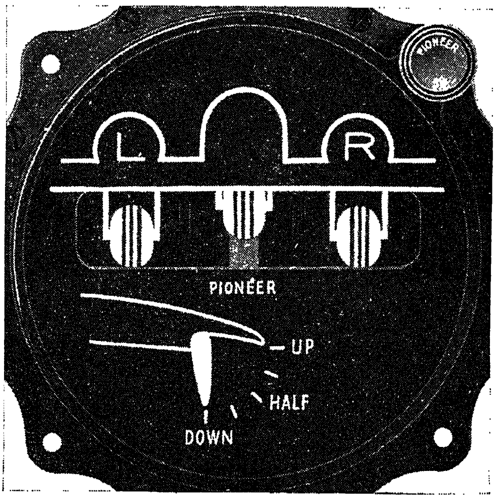


Figure 274. Type 6500-1A
(Pioneer Instrument Division of Bendix Aviation Corp.)

In the lower half of the dial is sketched the outline of an airplane wing. In its appropriate position is mounted a small luminously painted pointer, shaped to represent a flap.

When the instrument is operating the three small "wheels" and the "flap" move up and down exactly in step with their corresponding elements of the airplane.

Thus, in Figure 275, the wheels are fully retracted into the ship and the flaps are closed. In the center figure, the wheels are fully retracted but the right-hand main wheel is not locked "up."

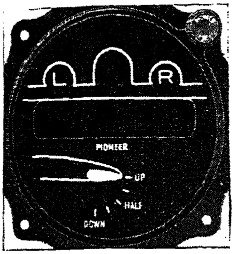
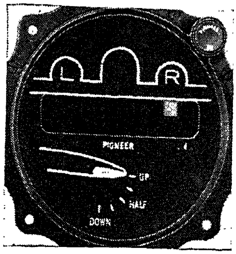


Figure 275. All Wheels Up and Locked, Flaps Up



In Flight

Figure 276. Right Wheel Unlocked

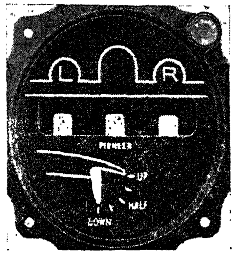


Figure 277. Power Off

(Pioneer Instrument Division of Bendix Aviation Corp.)

If, for any reason, the power supply to the system should be cut off, the three "wheels" would drop out of sight, leaving only three little tabs reading "off."

Figure 278 shows the indicator when the wheels and flaps are coming down. The left-hand wheel is down all the way and locked. Figure 279 shows all wheels down but the tail (or nose) wheel not locked down in place. Figure 280 shows the indicator with the flaps full down and all wheels locked down ready for landing.

For airplanes not equipped with retractable tail or nose wheel the indicator is available with only two wheel indicating flags.

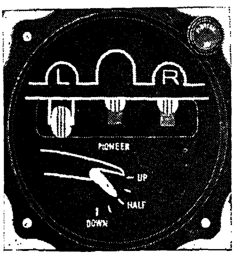
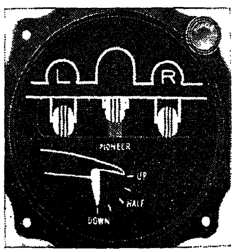


Figure 278. Left Wheel Down and Locked, Right and Tail Wheels Part Way Down, Flaps Part Way Down



Landing

Figure 279. Danger, Tail Wheel Not Locked

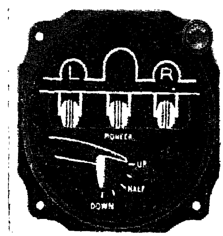


Figure 280. All Wheels Down and Locked, Flaps Full Down

(Pioneer Instrument Division of Bendix Aviation Corp.)

For installations which do not use wheel locks, transmitters are available with built-in step resistors for accelerated end travel. When these are used the red flag is visible until the wheel is almost up (or down). The last small motion of the wheel will cause the disappearance of the warning indicator.

There are two types of transmitter rotation available with this installation. The "−1" rotation requires a clockwise movement of the transmitter linkage fitting for an ascending or wheel up indication. The "−2" rotation requires a counter-clockwise movement of the transmitter linkage fitting for an ascending indication.

To assure adequate readability for night flying, the indicator is available with the Pioneer Ringlight. This system of individual instrument illumination provides a soft, evenly distributed light that completely activates the luminous paint with no perceptible glare.

Installation

Complete outline and wiring diagrams are shown in Figures 281 and 282. The wiring diagram is shown for a grounded DC system. The necessary connections for an ungrounded system are shown in dotted lines. The numbers shown on the wiring diagram correspond to the numbers on the terminal blocks and disconnect plug of the system.

The power supply is direct current of either 12 or 24 volts. The operation of this system is not dependent on a constant voltage supply and the usual ship supply variations will not affect it. The entire system draws about one ampere (at 12 volts).

The transmitters are connected to the flaps and retracting gear with a simple linkage that permits some range and zero adjustment. After installation the instrument is adjusted so that the individual "wheels" move in the proper positions as indicated on the installation instructions.

For maximum service life, it is recommended that the indicator be mounted on a panel suitably damped from vibration. The instrument should not be subjected to vibrations of more than 0.008″ total amplitude.

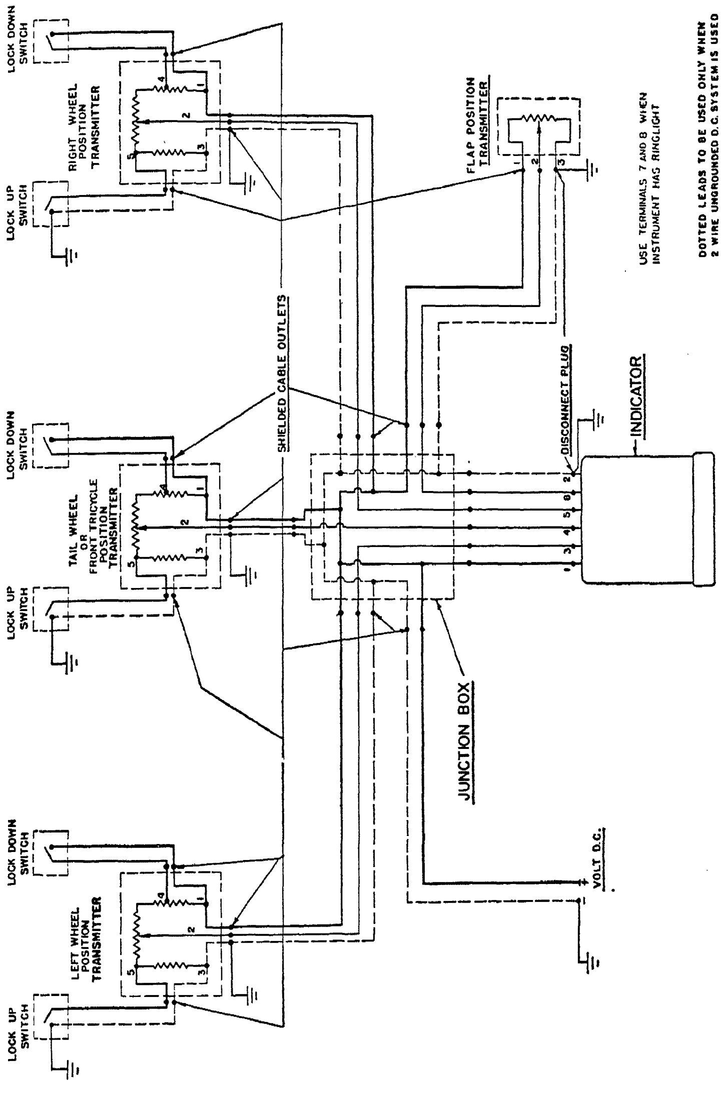


Figure 281. Wiring Diagram

Ringlight leads are included in the disconnect plug. Suitable resistors are built into the indicator to maintain the ringlight current to 0.2 ampere, when 12 volts are applied to the system.

Tests

The following tests apply to Type 6500 only. For all other types the manufacturer's test manual should be consulted.

Insulation Breakdown. 500 volts at 60 cycles per second shall be applied between the case and any terminal of the transmitter for one minute without causing any breakdown in insulation.

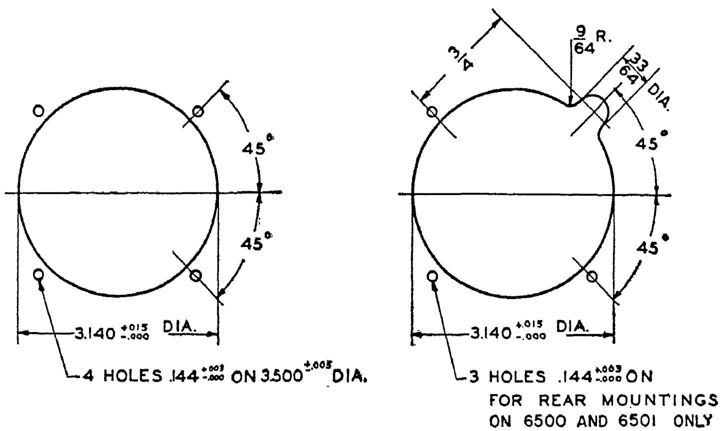


Figure 282. Panel Cut-Outs

Operation. Flap Indicator. With the transmitter in the extreme clockwise position (viewed from the shaft end), the indicator shall be in the "flap up" position $\pm 1°$. With the transmitter in the extreme counter-clockwise position, the indicator shall be in the "flap down" position $\pm 1°$.

Wheel Indicator. With the transmitter in the extreme clockwise position, only the complete lower tab of the indicator shall be in view $\pm 0.020''$. With the transmitter remaining in this position and terminals 3 and 5 shorted, the indicator flag shall disappear.

With the transmitter in the extreme counter-clockwise position (terminals 3 and 5 not shorted) the lower edge of the indicator flag shall be in line with the lower edge of window in the face $\pm 0.020''$. With the transmitter remaining in this position and terminals 1 and 4 shorted, the entire "wheel" section of the flag shall be in view $\pm 0.020''$.

With the power turned off, the indicator flag shall drop so that only the "off" tab shall be in view.

Friction. VIBRATION. The change in indicated position before and after vibrating the indicator shall not exceed 2° on the flap or 0.030″ on the wheel indicator.

POSITION. The indicator, with the flags in the "wheels-locked-up" position, shall be tilted sideways 30°, maintaining the dial in the normal vertical position. When the power is turned off, the flags shall fall to the "off" position with only very light tapping of the instrument. This test shall be made with both clockwise and counter-clockwise tilting.

CHAPTER 28

PIONEER OCTANT

The octant is used to determine position by using the sun, moon, or stars as references.

It consists substantially of a rotatable prism (9, Figure 284) rigidly connected to a worm arc meshing with a worm operated by a knob (1, Figure 283). The latter's periphery is divided into 10 major parts, each reading 1°, and subdivided into 12 parts, each reading 5′ of arc.

The limb of the arc is visible through the window (2, Figure 284) and carries a graduation line for each 10°. When reading the instrument, the tens of degrees are taken through the window, while the units of degrees and minutes are read directly from the micrometer drum.

The telescope system consists of an objective lens, a total reflection prism encased in the body, a bubble chamber assembly (4, Figure 283) including means for illuminating the bubble, and the eyepiece (5, Figure 283). The stationary prism (3, Figure 284) is used when taking sights on the sea horizon.

Artificial Horizon

The bubble chamber and the diaphragm chamber being component parts of a single piece of metal are extremely rigid. The bubble chamber, with glass top and bottom, forms a part of the optical system of the telescope. The two chambers, with a small connecting passageway, are completely filled with a transparent liquid. The knob (8, Figure 283) controls the position of the diaphragm, and thereby forms a bubble or controls its size.

For night observation two methods of illumination of the bubble are provided. Radium luminous material, painted on surfaces surrounding the transparent ring, furnishes light for

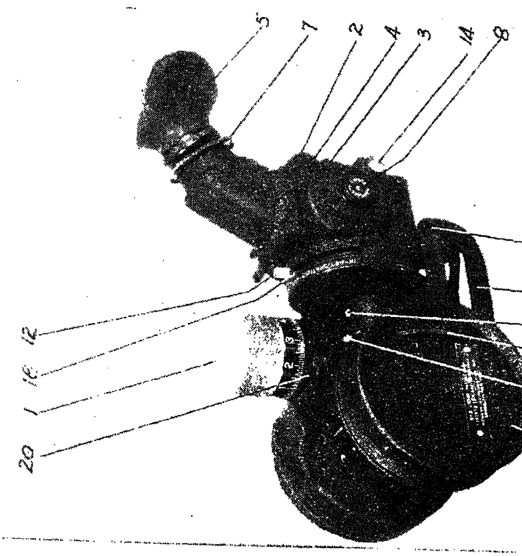


Figure 283

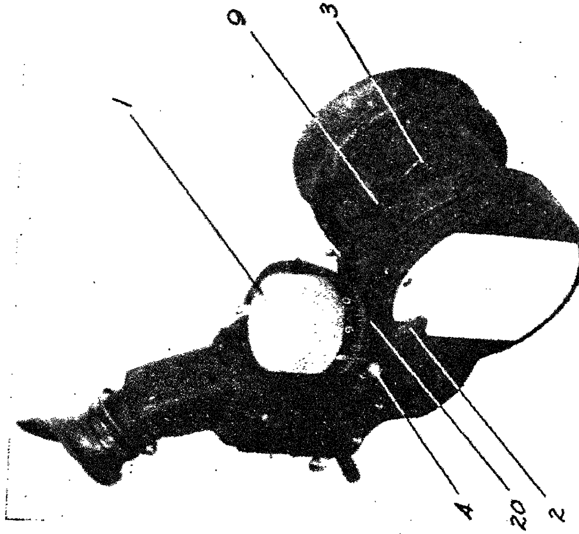


Figure 284

Pioneer Octant Type 1067C

illumination of the bubble. For still brighter intensity, electric illumination is provided. Immediately below the glass bottom of the bubble chamber is placed a ring of transparent material that reflects light gathered from the small electric light (2, Figure 283) upward. Inside the bubble chamber a reflector is so placed that the light from the ring is reflected uniformly, illuminating the bubble from the sides. The intensity of the light from the lamp may be controlled by rotating the disc (3, Figure 283) containing various size openings.

Eyepiece

The eyepiece consists of a prism and eye lens. It may be moved around the vertical axis, which permits the pilot to take observations to the rear in a comfortable position.

The eye buffer and eye lens are rotatable. The eye lens is adjusted for focus by rotation of the nut (7, Figure 283).

The telescope objective lens has a shutter which is operated by the knob (10, Figure 283). The shutter prevents vision through the fixed prism when the artificial horizon is used and when it is moved out of the way, permits the sighting through the same prism when the natural horizon is observed.

The rotatable disc (11, Figure 283) has several colored filters which are used when observing the sun and also a blank hole when observing the stars or moon.

A small knob (12, Figure 283) is used to operate the astigmatizer. The purpose of the astigmatizer is to elongate the image of the sun, moon or star, to a band of light about 3° long. This enables the bisecting of the bubble with the line formed by the astigmatizer which prevents the necessity of placing the image of the sun, moon or star side by side with the bubble on a horizontal level.

Optical Layout

Figure 285 gives a layout of the optics of the instrument. The purpose of each part is as follows:

The horizon and index prisms are both reflecting prisms. The direction of the rays of light which pass through the prism and

then through the objective, is determined by the position of the prism. Lines ABCDE and A'B'C'DE show paths of rays of light through the prisms for two different positions.

The objective lens causes the rays of light passing through it to come to a focus and form an image of the observed body at the bottom surface of the field lens.

The function of the astigmatizer lens has been explained above. Whenever the lens is thrown out of the optical path a parallel plate glass is substituted to compensate for a change in focal length.

The roof prism bends the rays of light through an angle of 90° and also both inverts and reverts the image (turns the image upside down and from right side to left and from left side to right).

The bubble bottom is a piece of parallel plate glass and serves as the transparent bottom for the bubble chamber.

The field lens forms the top of the bubble chamber, its under surface having such a curvature that the motion of the bubble, when the octant is tilted, is the same as that of the image of the celestial body. It also acts as a lens in the optical system.

The eyepiece prism bends the rays through an angle of 60°.

The eyepiece is adjustable in position for focusing the image and the bubble. It is of such a power that together with the other lenses of the system it gives a magnification of two diameters.

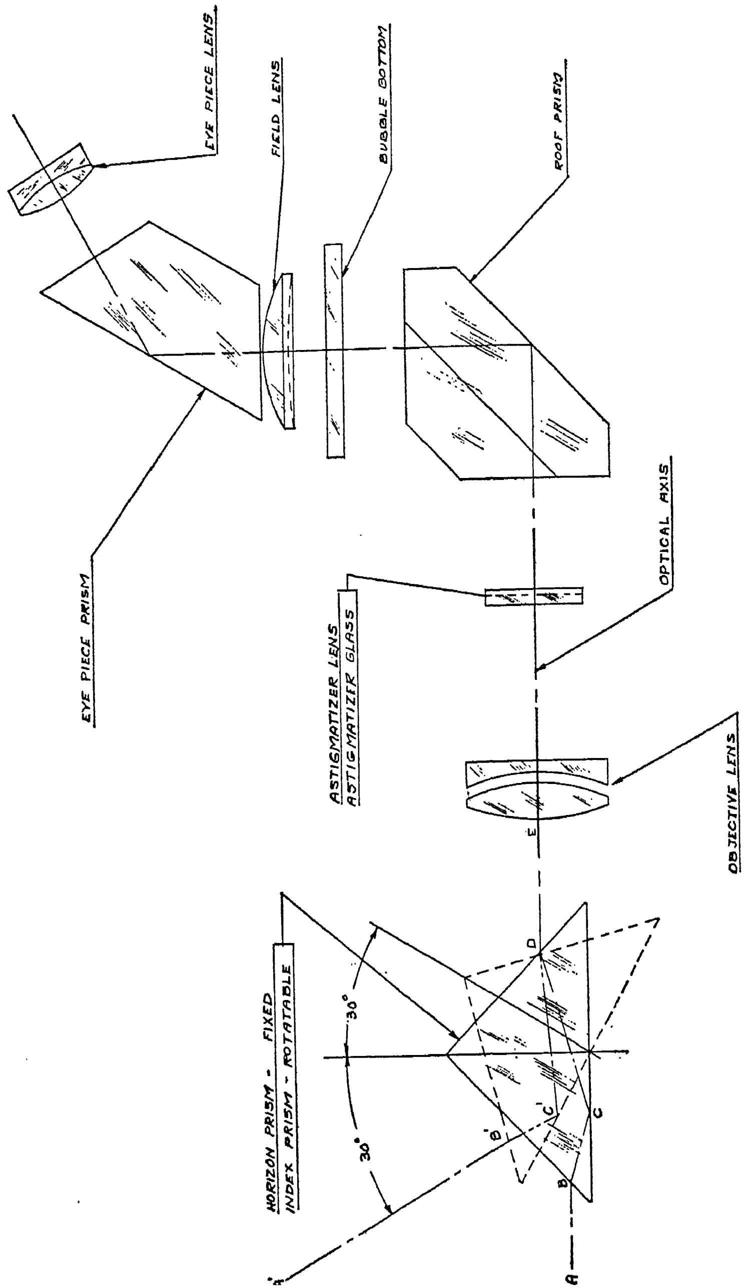
The image as observed through the eyepiece is fully erect.

Operation

The octant should be held in both hands.

The left hand operates the astigmatizer and the colored filters and the right hand operates the micrometer worm. The knob (10, Figure 283) is moved in the direction opposite to the arrow whenever the artificial horizon is used. This will prevent any horizontal light from coming into the telescope.

Before attempting to form the bubble or change its size, various characteristics of the bubble cell should be thoroughly understood.


EYE PIECE LENS
FIELD LENS
BUBBLE BOTTOM
ROOF PRISM
EYE PIECE PRISM
OPTICAL AXIS
ASTIGMATIZER LENS
ASTIGMATIZER GLASS
OBJECTIVE LENS
E
HORIZON PRISM - FIXED
INDEX PRISM - ROTATABLE
30°
30°
D
C'
C
B'
B
A

Opi

It frequently occurs that, due to conditions of pressure and temperature, a bubble is present in the diaphragm chamber independent of the fact that there may or may not be another bubble visible in the bubble chamber. This bubble in the diaphragm chamber is of such a size that it cannot pass through the connecting passage into the bubble chamber. Under these conditions, rotation of the control nut in the direction used to form the bubble will increase the size of the bubble already existing in the diaphragm chamber still more and make it impossible for the bubble to pass through the passageway and appear in the bubble chamber or to combine with the one already present.

The presence of the bubble in the diaphragm chamber can be easily detected by the significant reaction of the diaphragm to rotations of the control nut. Two cases should be distinguished:

A bubble is visible in the bubble chamber. A rotation of the control nut will change the size of this visible bubble slower than when no bubble is present in the diaphragm chamber due to the fact that the change in pressure is used to also change the size of the bubble in the diaphragm chamber.

There is no bubble visible in the bubble chamber. In this case the resistance felt when rotating the nut clockwise builds up gradually as contrasted to a sudden building up of the resistance when no bubble is present.

The above-mentioned facts suggest the following as the proper procedure to follow to form the bubble.

The first step should always be, even though a bubble is visible, to hold the octant with the control nut downward at an angle of about 45° from the vertical and rotate the nut *counterclockwise* sufficiently to put pressure on the liquid. If a bubble exists in the diaphragm chamber this will reduce its size and it may pass into the bubble chamber. If it does not, keep the control nut in this position for a minute or two and shake the instrument from time to time. This will cause any bubble entrapped in the diaphragm chamber to either disappear or become small enough to pass into the bubble chamber.

After this, if no bubble has appeared, hold the instrument in the inclined position and turn the control nut clockwise far

enough to just overcome the resistance which should build up suddenly. If this suddenly built-up pressure is overcome the bubble will form and is usually accompanied by a sharp click and the release of the resisting force on the control nut.

Immediately after this turn the control nut counter-clockwise again in order to apply some pressure on the liquid. This will prevent the formation of too large a bubble and reduce the size of those present in the diaphragm chamber so that they can pass into the bubble chamber. Rotation of the control nut back and forth several times, each time releasing the suction which is applied on the liquid is advisable and will speed up the removal of all bubbles from the piston chamber. The nut may now be rotated clockwise sufficiently to produce a bubble of the proper size.

Should the bubble not appear after this, start again from the first step.

In case it is desired to remove the bubble in order to make observations with the natural horizon, turn the control nut counter-clockwise to put pressure on the liquid and leave it in that condition for a minute or two. Shaking the instrument from time to time forces the bubble to move and thereby speeds up the condensation of the vapor bubble.

As the bubble appears, it may be compressed or expanded by turning the knob either way.

The optics of the octant are so designed that it is not necessary to match the image of the bubble with that of the sun or star in the center of the field. The matching or the "collimation" is shown in Figure 286, near the center of the field. The images of the sun and the bubble are aligned so that their centers are on the same horizontal line. It will not matter should the two images be collimated in the positions as shown in Figure 288 or 289. Should the two images be collimated as shown in Figure 290 the error will be about 5 minutes. The alignment as shown in Figure 291 will also give an error.

Figure 287 illustrates collimation when the sun is astigmatized. This method is preferred by many, since the symmetrical alignment of the two images makes it easier to determine the center of the bubble.

Figure 292 shows the horizontal arrangement of a star and the bubble and Figure 293 illustrates the astigmatized image of a star.

Stars are usually brought into collimation before astigmatizing and then the astigmatizer is switched on for the final adjustment, since they are not as plainly visible.

A bubble about twice the apparent size of the sun image or 1/10 of the size of the field will give the best results. The smaller the bubble the more slowly it will move, while a large

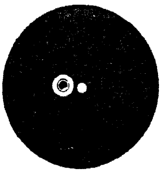


Figure 286

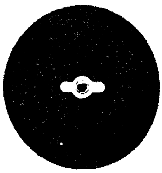


Figure 287

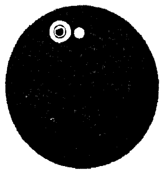


Figure 288

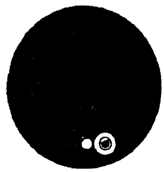


Figure 289

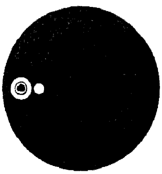


Figure 290

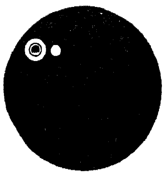


Figure 291

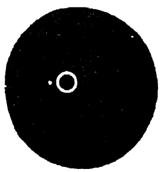


Figure 292

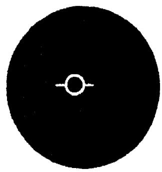


Figure 293

Matching or Collimation in Various Positions

bubble will be faster in its movements. Usually too small a bubble is avoided and the most suitable size bubble selected.

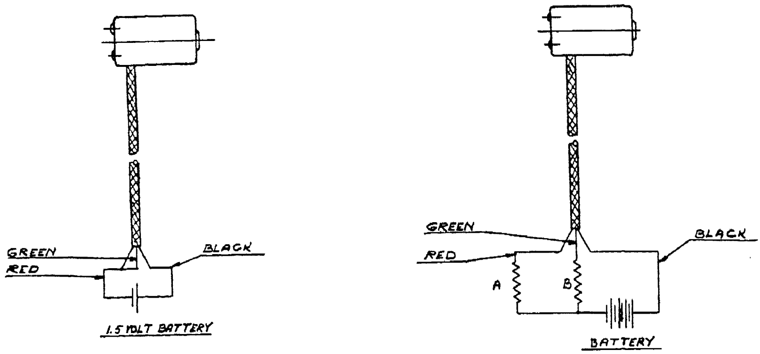
The horizon and index prisms are so placed that the fields through these prisms are visible simultaneously when the eye is placed approximately at the center of the eyepiece lens. If the eye is moved to the right side the index prism field is visible; to the left side, the horizon prism field comes into view. If the eye is moved from one side to the other there is a region in which both fields are visible.

For night work the light furnished by the radium luminous material is usually sufficient for illuminating the bubble. Should more illumination be necessary, electric illumination may be used. The switch (14, Figure 283) mounted on the back of

the telescope controls the light. The disc (3, Figure 283) when rotated, varies the intensity of illumination. Only sufficient intensity should be used as to make the bubble clearly visible.

The lamp for producing the illumination of the bubble is shown at 2, Figure 283.

A lamp has been provided for illuminating the graduations and the record pad. The lamp cap should be turned with the large slot toward the data pad.



BATTERY	A	B
12 V.	18.9 OHMS	59 OHMS
14.5 V.	23 OHMS	74 OHMS

Figure 294. Battery Connections
Showing the connections for 1.5 volt, 12 volt, and 14.5 volt sources of current.

The lamp holder will be found in a screw receptacle in the cover of the carrying case. It should be inserted in the threaded hole under the micrometer drum.

The battery (Bright Star No. 11 or equivalent) should be inserted into the holder under the telescope in the direction indicated on the clamp. It is not necessary to remove the paper jacket from the battery.

The contact button for the record pad lamp is located at the top of the left-hand handle.

After Using the Instrument, Turn Knurled Knob (8, Figure 283) in the Direction of Least Resistance Until It Feels Quite Free. This Is Done to Avoid Useless Strain on the Diaphragm.

A plug receptacle is provided for using a battery not mounted on the octant. It consists of a plug which fits into the battery holder on the octant and 8 feet of three-conductor cable. The plug must be placed with the end having the single contact in the direction indicated by the arrow on the battery holder clamp. For use with 1½-volt battery, the red and green colored leads should be connected to one battery terminal, the black lead to the other. For use with a higher voltage, resistances must be inserted in series with the red and green colored leads.

CHAPTER 29

AIRCRAFT BUBBLE SEXTANT

There are four commonly used methods of navigation—pilotage, dead reckoning, radio navigation, and celestial navigation. For high altitude and night flying, celestial navigation is used to a great extent. When forced to fly at an altitude of 15,000 or 20,000 feet the airplane will be above the clouds and the navigator will have an unobscured view of the heavens. Accurate observations and position determination can be accomplished by using the heavenly bodies as a reference.

The equipment used by most navigators is a (a) sextant, (b) timepiece, (c) almanac, (d) means for turning time and altitude into position.

It is not intended to present this section as a lesson in celestial navigation, but rather to explain the use and description of the sextant. To become a capable celestial navigator requires instruction and considerable practice.

The bubble sextant is intended primarily for use with aircraft. It serves well during the long period between evening and morning twilight when there may be stars in plenty but no horizon, and on those other occasions when the sun can be seen for moments only through rifts in the fog.

Self-Contained Horizon

A self-contained artificial horizon in the form of a bubble is used instead of the horizon. This bubble appears in the field of the sextant as a sharply defined circle to the center of which the heavenly body is brought to coincidence. The center of the field is indicated by a circle engraved on the bubble cell and, when the sextant is held exactly level, the bubble coincides with this circle. It is not necessary, however, to hold the bubble within this circle when making a coincidence between the heavenly body and the bubble.

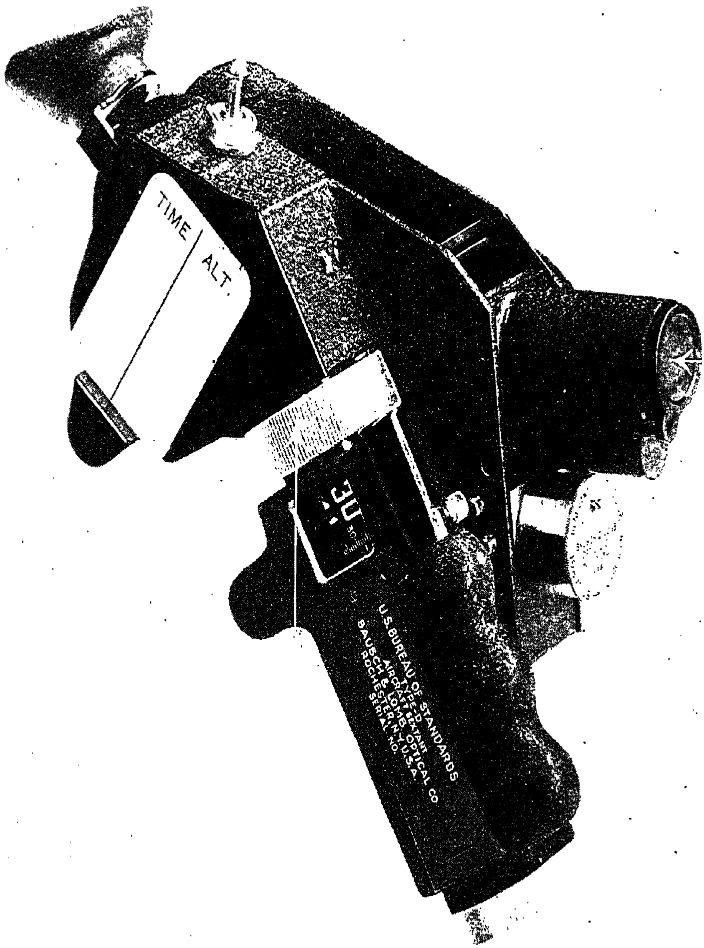


Figure 295. Bausch and Lomb Bubble Sextant
(Bausch and Lomb Optical Co.)

Coincidence

Coincidence may be made any place between upper and lower limits of the field without impairment of the accuracy. The bubble must not be permitted to touch the margin of the field which is established by the edge of the bubble cell, since contact will obviously interfere with the free play of the bubble. It is, therefore, not necessary to hold the sextant exactly level while making a coincidence between the heavenly body and the bubble, but only to be sure that the edge of the bubble does not touch the edge of the field. The engraved circle is useful for the purposes of adjustment and to indicate the center of the field as the preferred position in which to make the coincidence.

Mechanism. A worm and gear mechanism is operated by a knurled thumb wheel. This thumb wheel is placed at the top of

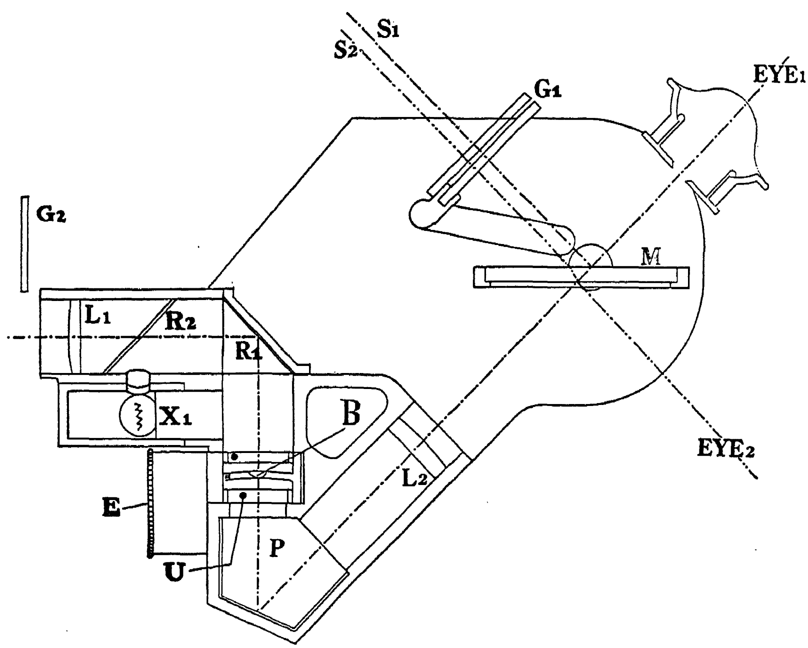


Figure 296. Diagram Drawing of Type D
(Bausch and Lomb Optical Co.)

the handle at the right side of the instrument in such a position that it may be operated with ease and precision when the instrument is held before the eye for observation. A counter mechanism of three graduated drums with large numbers and well-spaced graduations, permits the reading of the altitude to a single minute of arc. The drums and a conveniently located slate may be illuminated by an electric lamp.

Bubble Illumination

The bubble must be illuminated so that it may be seen in the field of the instrument. A single standard flashlamp dry battery is used as a source of energy, and the circuit passes through a two-way toggle switch at the top of the instrument within easy reach of the finger when the instrument is held in the operating position. One position of the switch illuminates the altitude drums and the record slate which is divided into two columns headed "Alt." and "Time." The other position of the switch energizes another bulb which illuminates the bubble through a rheostat located in the left handle of the instrument. The record slate is of ground glass with the headings and column line etched permanently into it so that erasure of old records may be made.

The battery is carried inside the right handle and may be replaced easily by removing a screw cap at the bottom of the handle.

Image Brightness Control

Two moderating glasses are supplied, one of such a density as to reduce the brightness of the moon to a degree comfortable to the eye. The introduction of both glasses provides a density such as to reduce the brightness of the sun to a comfortable degree. These glasses are those marked G_1 in the diagram. They may be introduced into and removed from the path of light by rotating a knob on the right side of the instrument. Another sun filter (marked G_2 in the diagram) is removably placed in front of the lens L_1. When the bubble is used as an artificial horizon this filter is in place. When the sea horizon

is used for making observations or for checking or adjusting the zero of the scale, it is removed from the path of light by simply swinging it out on a bearing.

Bubble Requirements

The bubble cell, of course, is the heart of any bubble sextant. In order that the bubble may play freely it is necessary to use a liquid that will be satisfactorily "quick" under all temperature conditions from arctic coldness to tropical heat. The only liquids meeting these conditions are the volatile hydrocarbons or mixtures of them, all of which have rather high coefficient of thermal expansion. Because of the required "quickness" these liquids will pass through the tiniest pathway, causing leakage and ultimate exhaustion of the liquid; also the high thermal expansion causes alteration in the size of the bubble with moderately large temperature changes. These two characteristics of the suitable liquids require that the bubble cell be perfectly leak-proof and be provided with simple and positive means for quickly altering the quantity of liquid in the cell. Failure to meet these conditions has been the greatest cause for dissatisfaction with bubble sextants in general.

Operation

Observations on the Sun or Moon Using the Bubble. The moderating glass or glasses G_1 are put into position. The filter G_2 is dropped over the lens L_1. The bubble is illuminated by throwing the toggle switch and adjusting the rheostat until the bubble B is satisfactorily illuminated. The eye is placed in the position EYE_1. Light from the bubble passes through the prism P and the lens L_2, through the index mirror M to EYE_1, which sees the bubble as if it were infinitely distant. Light from the sun or moon passes along the path S_1 through the moderating glasses G_1 to the index mirror M from which it is reflected also to EYE_1.

Now the image of the bubble and the image of the sun and moon will appear coincident when and only when the mirror M is at the correct angle of rotation about an axis perpendicular to

the paper. This rotation is accomplished by means of the knurled thumb wheel. When the images are in coincidence, the altitude may be taken from the counter drums.

Observations on Stars Using the Bubble. In this case the filter G_2 is also dropped over the lens L_2 but the moderating glasses G_1 are removed to their "out" positions. The eye now is placed at EYE_2. Light from the bubble traverses the prism P and the lens L_2 reaching the index mirror M whence it is reflected to EYE_2. Light from the star passes along the path S_2 through the index mirror M without change in direction to EYE_2. In this case also the star and the image of the bubble will appear infinitely distant. Coincidence is made as in the previous case.

Observations on Heavenly Bodies Using the Sea Horizon. In this case the filter G_2 is removed from in front of the lens L_1; the moderating glasses G_1 may be in or out, depending on the brightness of the heavenly body. In this case the lenses L_1 and L_2 constitute a unit power telescope presenting an infinitely distant image of the horizon to the eye either at EYE_1 or EYE_2. Coincidence with the horizon is made in the same manner by rotating the knurled thumb wheel.

Adjustments

The adjustments of the instrument are very simple and are three in number:

1. Adjustment of bubble size;
2. Adjustment to reconciliation between the sea horizon and the artificial horizon;
3. Adjustment of the scale zero.

The adjustment for 1 is carried out by rotating a knurled button on the bubble cell mounting in accordance with simple directions engraved on it.

The adjustment for 2 is a ground adjustment and is carried out by means of two capstan head screws on the bubble cell mount. This adjustment is necessary only when it is desired to use the artificial and sea horizons alternately without disturbing

the scale zero adjustment. It is a reasonably permanent adjustment and when carefully carried out aground will remain fixed over long periods. If all observing is to be done with either the bubble or the sea horizon, it need not be made.

The adjustment for 3 is carried out by setting the scale reading to zero, loosening a lock nut on the knurled thumb wheel and setting a coincidence to the sea horizon. Alternatively, a known altitude or an artificially established altitude (zero or not) may be used. The lock nut is then tightened.

CHAPTER 30

GATTY GROUND-SPEED AND DRIFT INDICATOR

The Gatty Ground-Speed and Drift Indicator combines the functions whereby both the ground-speed and drift angle of an airplane in flight may be readily determined. The indicator may be as readily used over water as land. An hour's continuous practice over land is all that will be required to make the observer proficient in its use; after which, with a little practice over water, the use of the instrument will have been entirely mastered.

Ground-Speed Indicator

The basic principle involved in the design and use of this instrument as a ground-speed indicator is the solution of similar triangles. This is accomplished practically automatically by the indicator. It functions as follows: A grid in the form of an endless ribbon, referred to as the "grid ribbon," is caused by clockwork mechanism to travel across the field of view at a predetermined speed. Through the openings in the moving ribbon, the apparent ground movement is at the same time observed. The eyepiece, through which the two motions are simultaneously observed, is adjusted up or down, until the speeds of both ribbon and ground appear to coincide. The ground speed can then be readily determined by the simple process of dividing the altitude above the observed surface by the figure indicated on the counter alongside the eyepiece slide. (A chart may also be used for this purpose.)

For the sake of greater flexibility and accuracy, the grid ribbon can be caused to travel across the field of vision at any one of three predetermined speeds. The counter, above referred to, is therefore composed of three separate sections; one set of figures for each of the three ribbon speeds. With these ribbon

speeds, the entire range of practical flying speeds of airplanes can be taken care of.

Any of the three ribbon speeds can be selected at will by pulling a gearshift pin (C) to the proper position, in, out, or at the middle point.

In computing the ground-speed, it is only necessary to read the figures on the counter which is marked corresponding to the position of the gearshift pin (C). For example, when the gearshift pin is pulled all the way out, read the figures on the counter marked "OUT"; when the gearshift pin is pulled but midway out, read the figures on the counter marked "MIDDLE"; and when the gearshift pin is all the way in read the figures on the counter marked "IN". The gearshift pin "C" will be in the MIDDLE position when the shoulder where the diameter of the pin becomes smaller, is approximately flush with the side of the case. Construction of gearshift is such that while pin C slides freely, it will remain securely in place in any of the three positions.

The following table, showing the recommended ribbon speeds for the various flying speeds and altitudes, will be found useful for beginners, though with a little practice the proper ribbon speed to use under the various flying conditions encountered, will soon become apparent.

		At approx. speed of:		
		60 m.p.h.	110 m.p.h.	160 m.p.h.
		Good for Altitudes (in feet)		
Using "IN" speed of ribbon,	1.012″ per sec.	250–1,000	400–1,800	600– 2,650
Using "MIDDLE" speed of ribbon,	.506″ per sec.	450–2,000	825–3,625	1,200– 5,300
Using "OUT" speed of ribbon,	.253″ per sec.	900–4,000	1,650–7,250	2,400–10,550

There is nothing complicated about the use of the indicator. All the constants in the formula for the solution of the two similar triangles involved, have been mechanically incorporated. The one variable is the *altitude above the observed surface.*

The formula is as follows:

$$A : H :: GS : RS$$

Where A = Altitude above observed surface.
H = Height of eye above ribbon.
GS = Desired ground-speed.
RS = Ribbon speed.

A moment's study of the diagram, Figure 297, will show that the greater the height of the eyepiece above the ribbon, the greater will be the accuracy of the derived ground-speed.

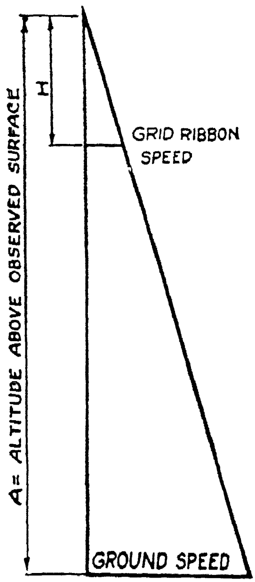


Figure 297. Installation, Mounting and Care of the Gatty Ground-Speed and Drift Indicator

The instrument is made to be mounted on the right side of the fuselage of an airplane (right side, looking forward) and should be mounted so it will be on the right side of the navigator or observer. (The use of the instrument by the pilot, while flying the ship, is not recommended.) The instrument should be mounted on a suitable bracket, with the outer prism projecting through an opening in the side of the fuselage, far enough to have an unobstructed view of the ground below.

The instrument is to be mounted horizontally in the flying position of the plane; and the outer prism must also be aligned parallel to the fore and aft (or longitudinal) axis of the plane.

Since each type of airplane will require a different type of bracket for mounting, no bracket is standard. A strong, firm bracket, that will be free from excessive vibration, will be

found most suitable. A type of bracket recommended is shown in Figure 298. The mounting should be at a height convenient to the navigator while seated. Two holes are to be drilled and a center recess milled in the bracket, to receive the two mounting screws (with wing nuts) and dowel pin.

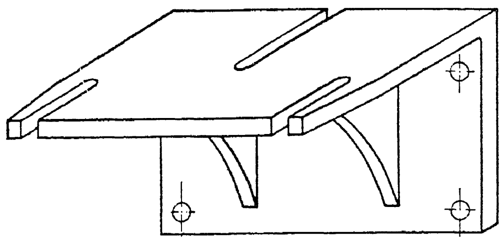


Figure 298. Suggested Type of Supporting Bracket

In a seaplane, or amphibian, a rectangular slot may be cut in the hull above the waterline, of sufficient size to allow the large prism to pass through. It is recommended that this be made a permanent and watertight installation; and that the large prisms be sealed around the edges. If preferred, however, slots may be cut in the bracket, which will permit the instrument being withdrawn inboard when landing on water; while a hinged flap fits over the rectangular hole in the hull.

Adjusting the Instrument

After the instrument is mounted in place in the airplane, see that the large, or outboard, prism is aligned parallel to the fore and aft centerline of the airplane. This can easily be accomplished by drawing a line on the ground, parallel to the centerline of the ship, and approximately under the outboard prism.

At the same time, the drift grid can be adjusted parallel to the fore and aft centerline of the plane and the dial reading set to zero. To do this, turn the knurled knob (B) until the grid is in alignment parallel with the centerline of the plane. With the special wrench furnished with each instrument, loosen set screw in knob (B), set dial to read 0, and tighten set screw. (See Figure 300.)

The grid ribbon should have a travel of one complete revolution in 36.48 seconds in slow or OUT speed—that is, when the gearshift (C) is pulled out as far as it will go. If it is necessary to make any adjustment in the speed of the ribbon, the clockwork mechanism is to be withdrawn as a complete unit from the case (by removing the four screws A) and then turning screw (G), on the under side of the governor mounting. (See Figure 299.) Turn screw G, clockwise to increase the speed, and counter-clockwise to decrease the speed. This adjustment is very sensitive, and but very little movement will be required.

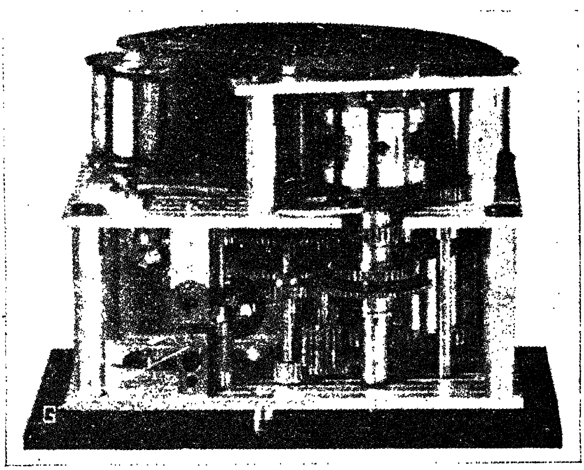


Figure 299. Internal Mechanism of the Instrument

Should it ever be found necessary to adjust the reading of the counters (OUT, MIDDLE, IN) of the eyepiece slide, move the slide down as far as it will go, and clamp in place, by means of the clamp screw on the under side of the instrument. Remove the cap (E), and with the key (furnished with the instrument), turn the shaft, with the square end, one way or the other, to the proper reading.

The ratio between the readings on the three counters being fixed, it is only necessary to adjust any one of the counters.

The reading on this particular instrument, on the OUT

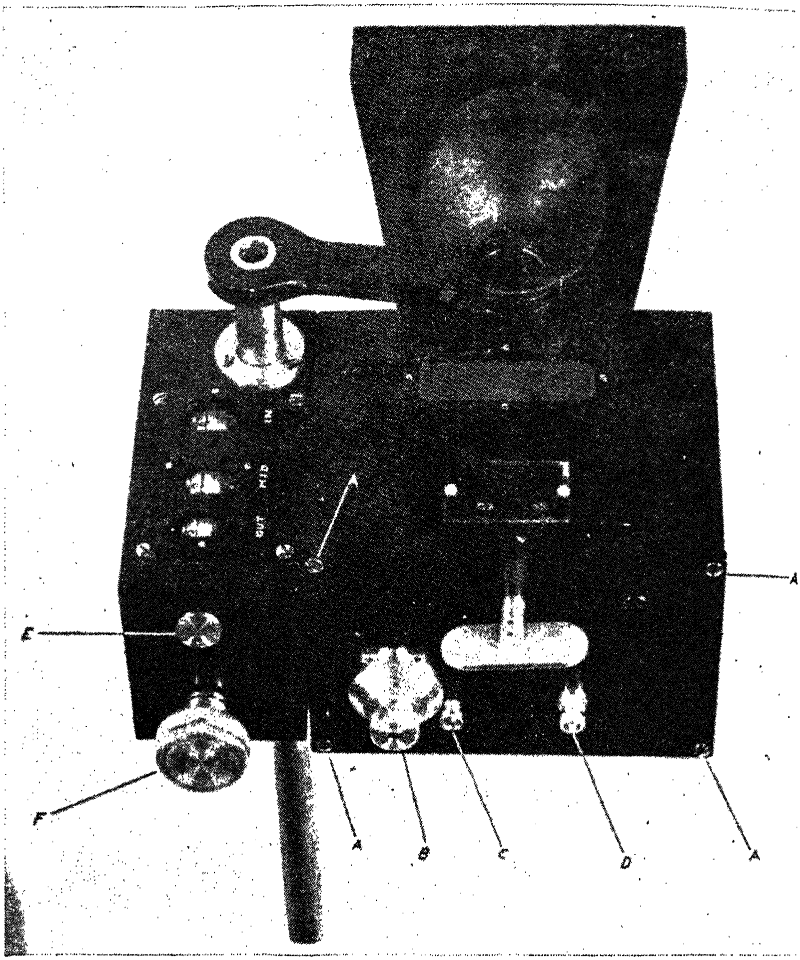


Figure 300. External View

counter, has been set at the factory to read ( ). This will be found suitable for the position of the average observer's eye, over the eyepiece.

Operation

As soon as the instrument has been mounted and adjusted, it is ready for operation.

To Determine Ground-Speed. First, wind clockwork mechanism, turning key in a clockwise direction. Next, start grid ribbon in motion by pulling out knob (D) as far as it will go. Place the eye comfortably close to eyepiece, and move the slide up or down, by means of the rotating knob (F), observing the apparent motion of the surface below through the travel of the grid ribbon. (Over the water, either white caps or reflected sunlight may be observed.) When the speeds of both ground and grid ribbon appear to coincide, clamp the slide in place, by means of the clamp screw on the under side of the instrument. Press in knob (D), to stop clockwork mechanism, and read the number on the proper counter. (OUT, MIDDLE, or IN, as already explained.) Divide the ALTITUDE ABOVE THE OBSERVED SURFACE by the reading of the proper counter; the result will be the ground-speed in miles per hour, *on the heading of the ship.*

Drift Indicator. To get the true ground-speed, we must first determine the drift of the plane. (Grid ribbon may remain stationary.)

While the ship is in flight, sight down through the eyepiece and pick out objects in the field of view. Follow their travel along the wires of the DRIFT grid. By rotating knob B (Figure 300), swing the drift grid to the right or left, until the objects sighted appear to travel continuously along the wires of the grid. Read the angle of drift on the dial of the knob B, either plus or minus. (A plus reading is added to the course while a minus reading is subtracted.)

With this angle, and the previously determined *apparent* ground-speed, enter the accompanying table, and read the *true* ground-speed.

A curve may be arranged to take the place of the table.

Caution: Be sure to read the figures on the counter corresponding to the speed of the grid ribbon. The words "OUT," "MIDDLE," and "IN," refer to the positions, respectively, of the gearshift pin (C), as explained earlier in this book.

CONVERSION TABLE

APPARENT GROUND-SPEED TO TRUE GROUND-SPEED

Drift Angle	APPARENT GROUND-SPEED MILES PER HOUR														
	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
	TRUE GROUND-SPEED														
5°	80.3	85.3	90.4	95.4	100.4	105.4	110.4	115.4	120.5	125.5	130.5	135.5	140.5	145.6	150.6
10°	81.2	86.3	91.4	96.5	101.5	106.6	111.7	116.8	121.9	126.9	132.0	137.1	142.2	147.2	152.3
15°	82.8	88.0	93.2	98.4	103.5	108.7	113.9	119.1	124.2	129.4	134.6	139.8	144.9	150.1	155.3
20°	85.1	90.5	95.8	101.1	106.4	111.7	117.1	122.4	127.7	133.0	138.3	143.7	149.0	154.3	159.6
25°	88.3	93.8	99.3	104.8	110.3	115.9	121.4	126.9	132.4	137.9	143.4	149.0	154.5	160.0	165.5

CHAPTER 31

OXYGEN REGULATOR

The quantity of oxygen which is absorbed in the blood stream is dependent on the atmospheric pressure. Since it is known that pressure and density decrease with altitude, the deficiency of oxygen must be overcome by supplying the required amount. At 18,000 feet the atmospheric pressure is about one-half of that at sea level and therefore about one-half as much oxygen is obtained during each inhalation.

Experiments have shown that at altitudes above 18,000 feet a person's physical and mental condition is affected unless some means is provided to supply oxygen.

Operation

The oxygen regulator is a sensitive metering instrument which controls and regulates the flow of oxygen from the supply tank to a mouthpiece or mask under high pressure (Figure 301). Two pointers indicate over separate scales on the dial; the pressure condition in the supply tank is shown on the lower scale and the flow of metered oxygen on the upper scale.

The flow scale is calibrated directly in altitude. That is to say, for a set indication the flow is automatically regulated to supply the correct quantity of oxygen at that altitude. The calibration of the instrument is shown on the flow charts, Figures 303 and 304, the curve of flow indicating the established requirements for one man at the altitudes shown.

The schematic drawing, Figure 302, illustrates the operation principles of the oxygen regulator. The instrument is divided into a back chamber and the front gauge compartment. Oxygen enters the back chamber from the supply tank under the control

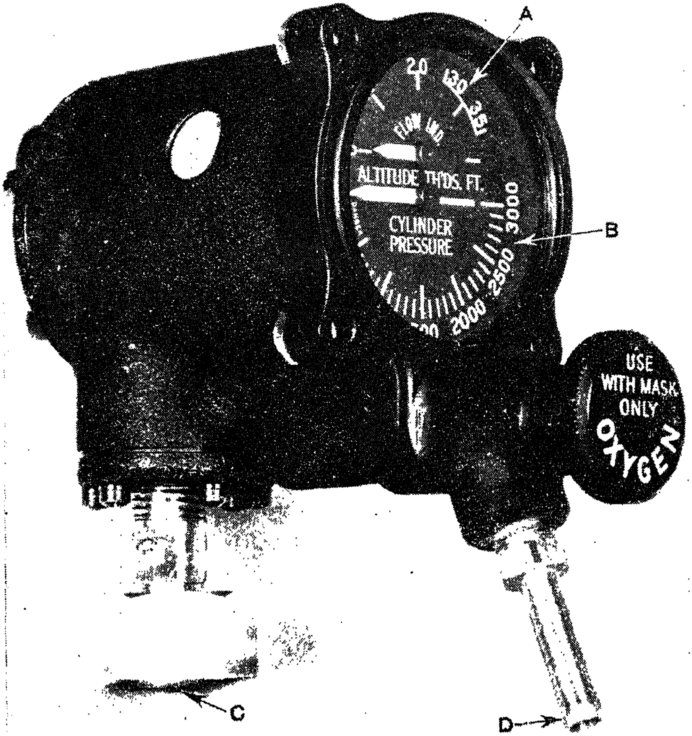


Figure 301. Oxygen Regulator
(Pioneer Instrument Division of Bendix Aviation Corp.)

A—Flow-Meter Scale
B—Cylinder Pressure Scale
C—Connection to Oxygen Supply
D—Connection to Mask

of a regulating valve. This valve is operated by a spring-restrained diaphragm through a toggle link mechanism and automatically maintains a constant reduced pressure in this chamber throughout the wide operating pressure range of a standard supply cylinder. The valving action is extremely accurate. A small force on the diaphragm caused by a slight variation of pressure exerts, through the toggle links, a greater force on the valve seat, thereby insuring positive pressure control and definite shut-off of the supply for no flow conditions.

From the back chamber, the oxygen flows through a needle valve, which is manually operated by a knob from the front

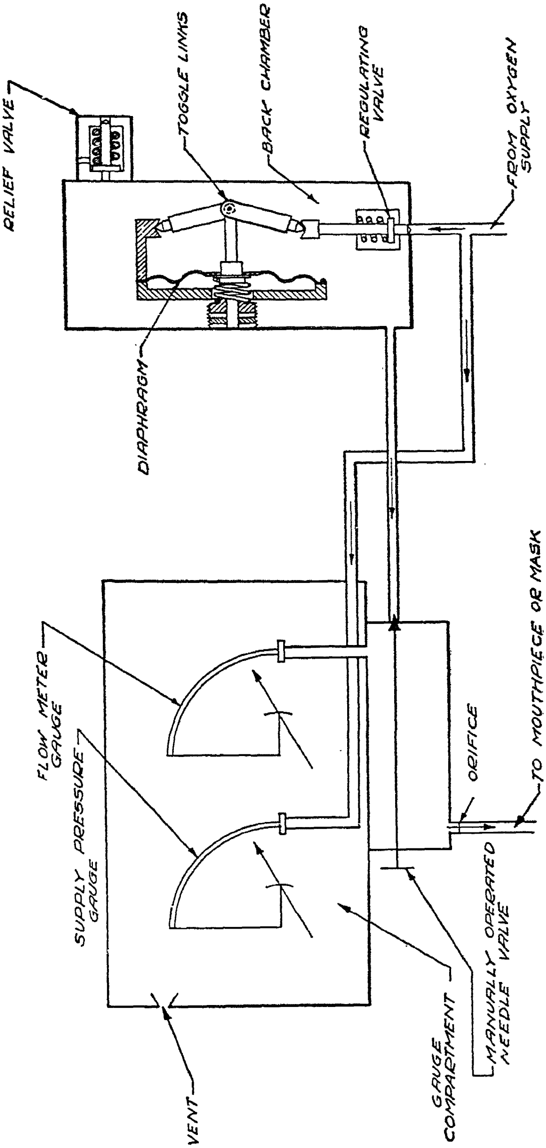
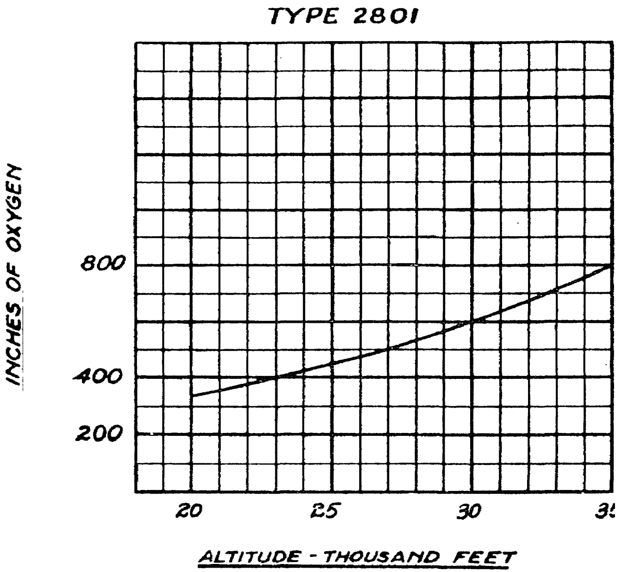
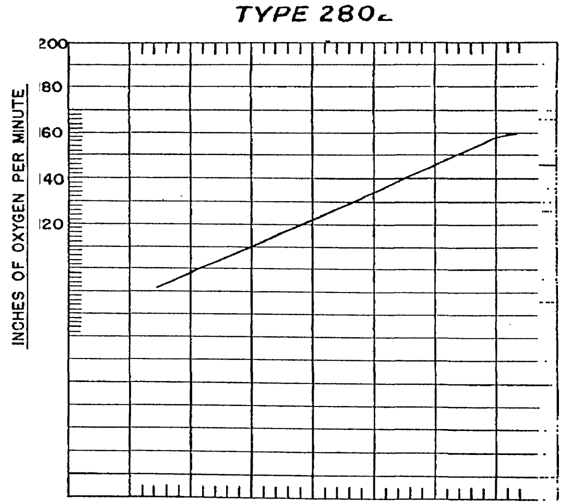


Figure 302. Schematic Drawing of The Oxygen Regulator





Note
This curve is the flow in cubic inches of oxygen per minute obtained by operating the valve so as to bring the flow pointer to the indicated altitude—the altitude corresponding to pressure conditions under which the instrument is operating.

Figure 303. Type 2801 (Pipe Stem Mouthpiece)

Figure 304. Type 2802 (Mask)

of the instrument. From this point, a calibrated orifice meters the flow to the mouthpiece or mask. The flow indicator, a Bourdon tube pressure gauge, indicates directly the pressure differential across a calibrated orifice and is calibrated to indicate the flow corresponding to this pressure differential. The dial is marked directly in altitude for simplification, the proper flow for any altitude being obtained when the pointer is set at corresponding graduation by opening or closing needle valve.

The cylinder pressure indicator, also a Bourdon tube type, is connected directly to the line from the oxygen tank. This unit shows the exact condition of the supply at a glance.

A relief valve on the rear cover of the case is a safety feature that prevents overpressure in the rear chamber, and damage to the mechanism, should the regulating valve be temporarily held open for any reason.

The pressure stage in the back chamber is automatically controlled and has complete temperature compensation.

In the capillary tubes to the gauge units, the pressure is static as there is no flow. Should a leak occur in the gauge, it would not be serious, as the small bore tubing would retard the flow through a leak and prevent building up of pressure in the vented gauge compartment.

Testing—Types 2801 and 2802

Individual Tests. PRESSURE GAUGE TEST. The regulator shall be connected to a suitable source of oxygen pressure and the gauge checked against a master pressure gauge at each 500 lbs. (50 kg.) graduation, up to 3,000 lbs./sq. in. (0-200 kg./sq. cm.). The error at each test point shall not exceed ±100 lbs./sq. in. (±5 kg./sq. cm.).

LEAK TEST. The regulator shall be connected to an oxygen cylinder containing at least 1,500 lbs./sq. in. pressure. When the oxygen is turned on at the cylinder, there shall be no leak through the needle valve; when it is shut off, at any gasket or through the relief valve.

FLOW TEST. The metering valve shall be opened successively to the following indications and the flow of oxygen

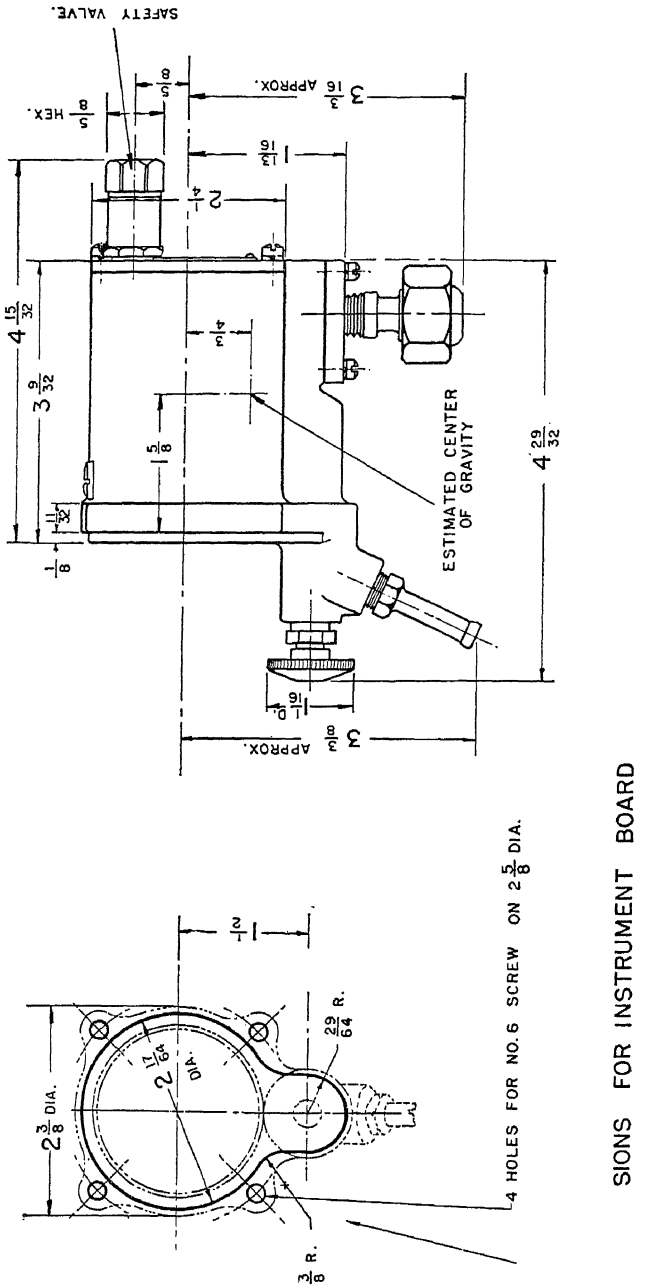


Figure 305. Oxyg Dimensio
This outline drawi and 2802

checked by means of a flow-meter or other suitable apparatus. The setting and oxygen flow shall be as follows:

TYPE 2801

Altitude Setting Feet	Sea Level Flow Cu. in./Min.	
20,000	400	± 80
25,000	700	± 140
30,000	1100	± 220
35,000	1400	± 280

TYPE 2802

Altitude Setting Feet	Sea Level Flow Cu. in./Min.	
10,000	117	± 17
20,000	166	± 20
30,000	214	± 21

The flow gauge pointer shall move smoothly through 180° ± 5° from zero as metering valve is opened for any cylinder pressure from 500 to 3,000 lbs./sq. in. (35 to 200 kg./sq. cm.).

Installation

The regulator is designed for panel mounting. To install, first cut two holes, one 2 17/64″ and the other 29/64″ in diameter on a vertical center line 1½″ apart, as shown on the outline drawing and shape to provide for the indicator: Drill mounting screw holes on a 2⅝″ diameter to provide for four #8 mounting screws.

Care should be exercised to insure leakproof connections between the oxygen tank and the regulator. All regulators are equipped with high strength fittings for connection to standard oxygen tanks. Sufficiently rigid mouthpiece or mask tubing should be used to prevent crimping or restricting the oxygen flow in any way.

For the most satisfactory operation, the oxygen regulator should be installed so that it is not subject to a vibration in excess of 0.020″ at ordinary engine frequencies.

CHAPTER 32

ANTI-VIBRATION MOUNTING OF AIRCRAFT INSTRUMENTS

The initial step in the maintenance of aircraft instruments is to provide an anti-vibration mounting for them. Without the proper mounting, the life of the instruments is materially shortened and overhaul periods are frequent. With the proper anti-vibration mounting the instruments will generally outlive the airplane.

Modern instruments are light in weight, rather small in size, are required to be extremely sensitive in indication and are operated by small forces.

Furthermore, the mechanisms of most instruments are perfectly balanced in construction and must remain so if the indications are to be accurate. The end to end play or clearances of various moving parts are as close as 0.001″ and several Sperry tolerances are even closer. It is obvious that in order to maintain specified tolerances and balance the instruments should not be subjected to extreme vibrations or shocks.

Vibration forces are constantly changing in magnitude and direction. If the instruments are subjected to these forces, pivots striking their ball races will develop low or flat spots, jewels may be broken by pivots, pivots will become dulled; all of which will necessitate a premature overhaul of the instruments.

The proper functioning of the airplane radio equipment will likewise be affected.

By continual tests and observations, aviation engineers have found that a full vibration amplitude of less than 0.004″ will have very little effect on the instruments. There are very few airplanes so inherently smooth; if there were it would still be wise to shock mount the panel to offset the landing shocks.

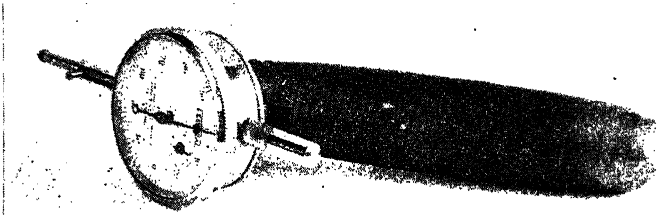


Figure 306. Vibrometer for Measuring the Amplitude of Vibration of the Instrument Panel

The instrument shown in Figure 306 has a precision indicating gauge graduated in 1/1000″. The heavy handle weighs about 5 lbs.

The vibrometer is held lightly in the hand. The weight of the handle and of the hand has sufficient inertia to remain

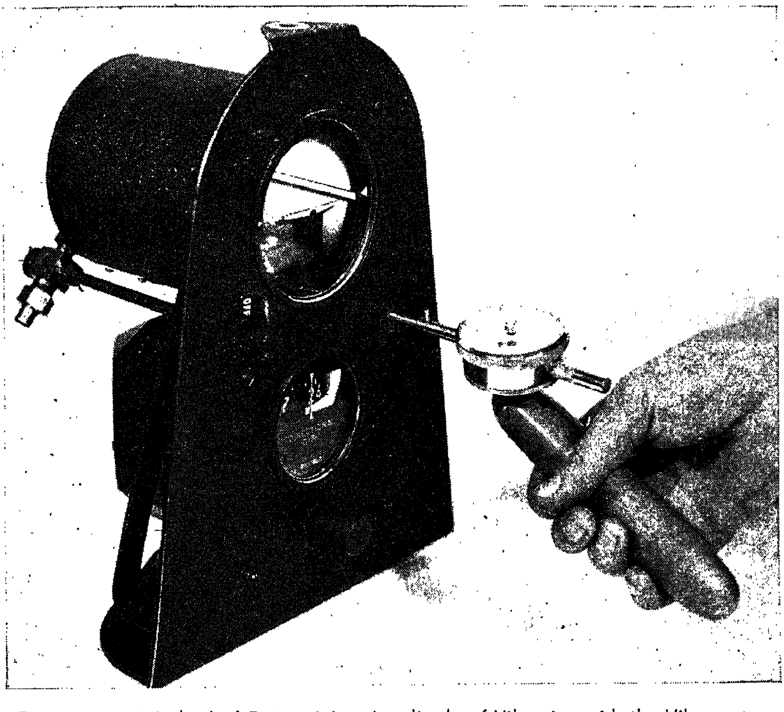


Figure 307. Method of Determining Amplitude of Vibration with the Vibrometer

steady for a short time. The instrument is held lightly against the panel and due to the rapid movement of the pointer (30 oscillations per second) a grayish arc will be formed, which can be read as close as 0.0005″. Usually, readings are taken on several sections of the panel and noted, for further reference when shock mounts are installed.

Lord Mountings

The shock mounts in Figures 308, 309, and 310 consist of steel monel or brass plates to which the rubber body is bonded. The steel center pins are also bonded to the rubber. Each mount

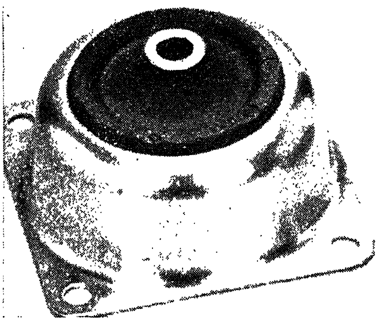


Figure 308. Holder (PH) Type

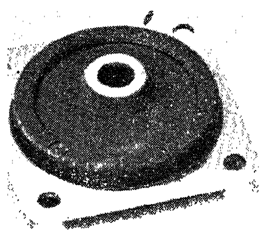


Figure 309. Square (P) Type

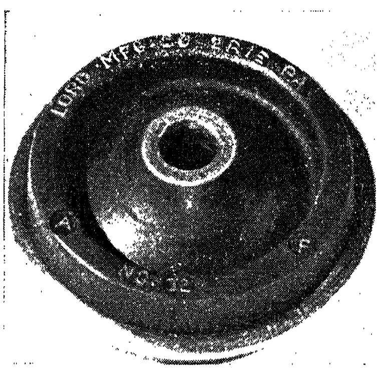


Figure 310. Round (PR) Type

SHOCK MOUNTS

has a load side on which is stamped a number corresponding to the number of pounds load, which will cause the mount to deflect 1/16″. The mountings are rated at 1/16″ deflection for comparison of stiffness. Usually the mounts are mounted in pairs as shown in Figures 312 and 313 giving a 1/8″ deflection.

Rubber when mounted in shear has the ability to absorb vibration better than when mounted in any other way. It gives a soft rate of deflection, provides a low natural frequency and presents an initial tension to the rubber, making it several times stiffer radially than axially. This reduces the amplitude greatly at resonance and damped out repeated oscillations.

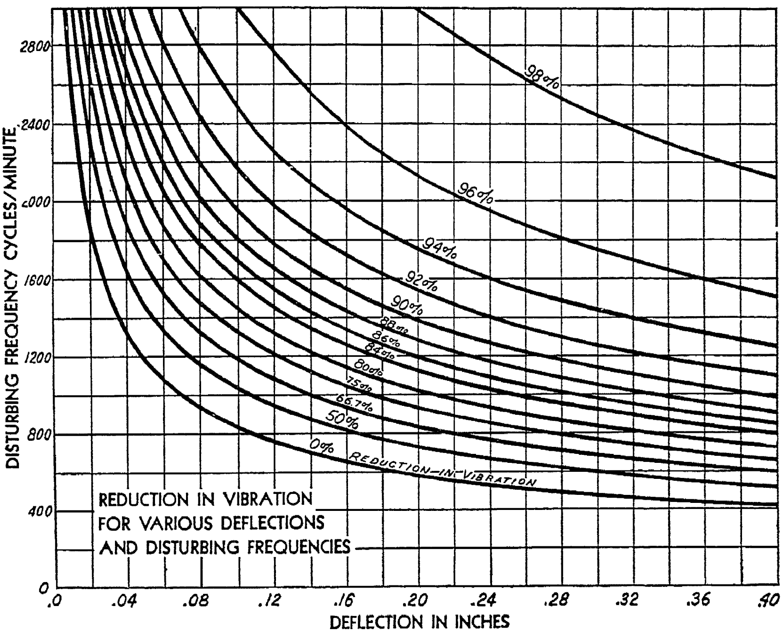
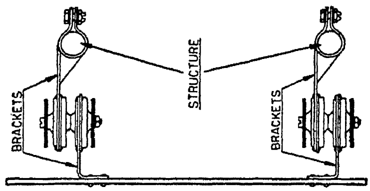


Figure 311. Curve Showing Deflection in Inches and Disturbing Frequency

The curve, Figure 311, gives a convenient means of determining the deflection required for a satisfactory degree of vibration absorption for a known disturbing frequency. For disturbing frequencies of 1,750 cycles per minute or higher, approximately 1/16″ deflection provides adequate vibration absorption. For lower disturbing frequencies correspondingly



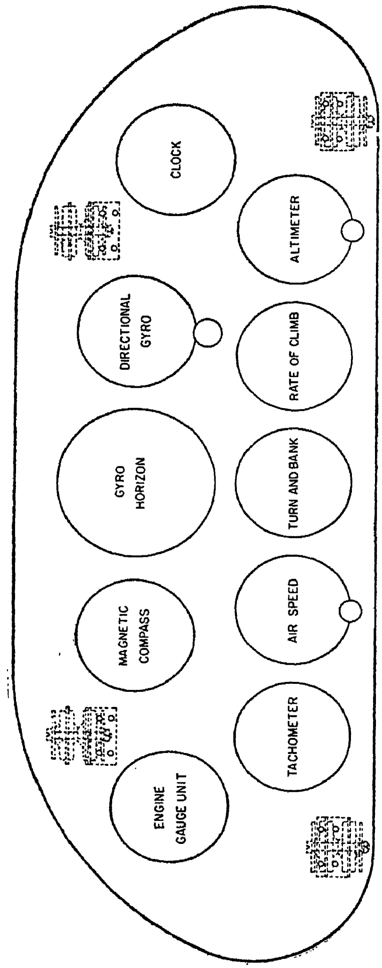


Figure 312. Complete Panel on Anti-Vibration Mounting

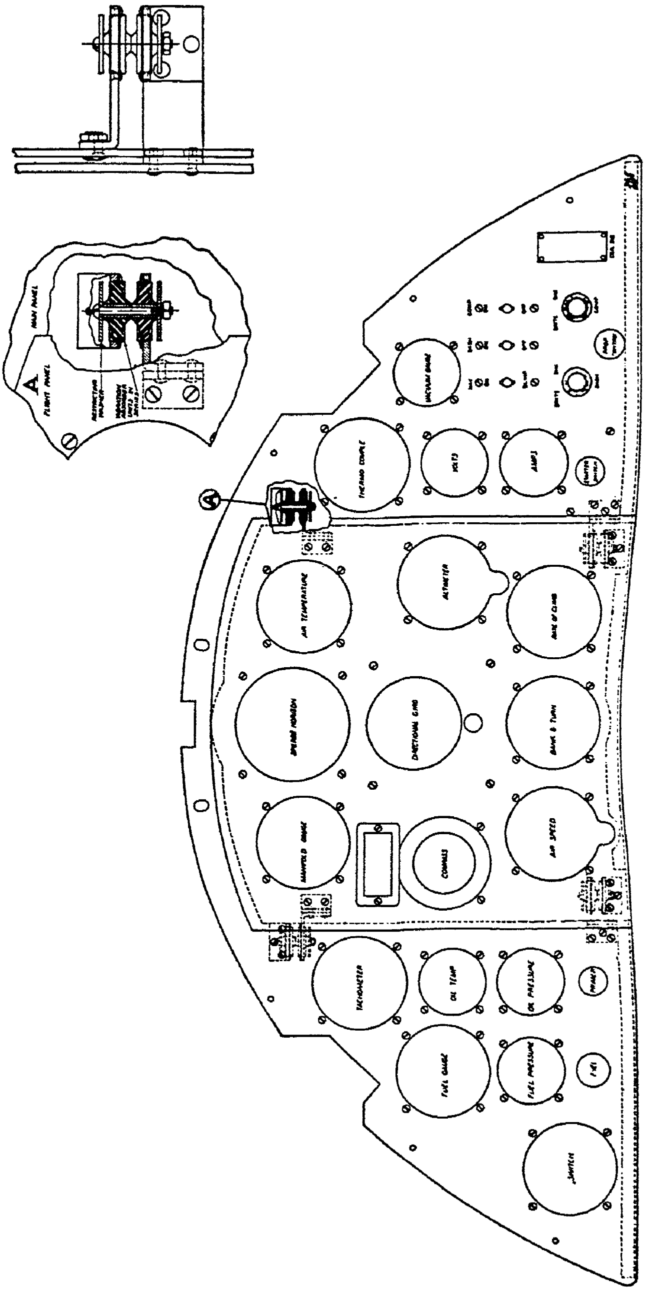


Figure 313. Method of Shock-Absorbing Flight Instrument Panel Separately

greater deflections will be required to absorb the vibratory forces.

A comparison of normal and maximum load ratings in the chart shows the following facts about these plate form mountings:

100 series can be loaded only to normal loading.
150 series can be loaded to 150% of normal loading.
200 series can be loaded to 200% of normal loading.

Under normal loading each type of mounting will deflect 1/16″, but under maximum loading

100 series will deflect 1/16″ under maximum load.
150 series will deflect 3/32″ under maximum load.
200 series will deflect ⅛″ under maximum load.

For example, the 150-P-8 mounting is rated at 1/16″ deflection under 8 lbs., but is capable of carrying up to 12 lbs. at which the deflection is 3/32″. The larger deflections possible with the 150 and 200 series mountings make possible an increase in the degree of vibration isolation for any set of conditions as shown by the curve, Figure 311.

The 200-XP series, while having a higher normal rating than the 200 series, cannot be loaded above 120 lbs. This figure of 120 lbs. is the maximum load which can be supported on this type of mounting, since the stress per square inch of bond area on the outer plate becomes excessive beyond this maximum loading.

The above series numbers may be slightly confusing at this point but are clarified in Figure 314.

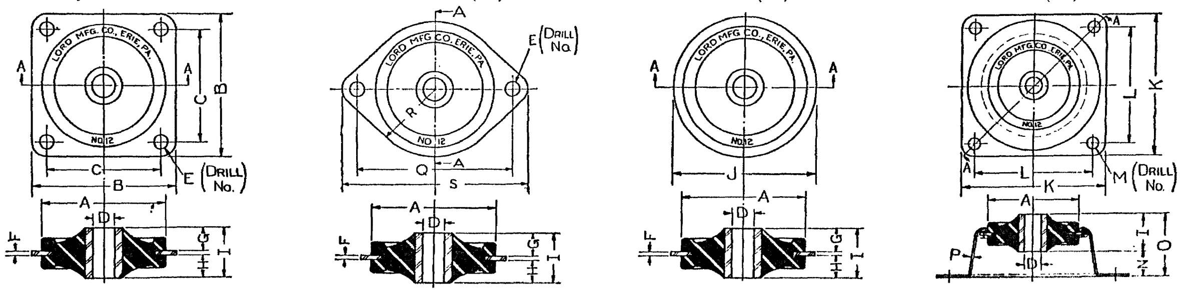
Rules for the Insulation of a Panel against Vibratory Disturbances

(a) The panel should be constructed of metal sufficiently rigid to prevent flexual vibration. The minimum thickness should be 0.125″ for aluminum and 0.095″ for dural. Where the panels are large, strips of "L" or "Z" channels should be riveted to the back of the panel to assure rigidity.

Normal Rating @ 1/16" Defl.	Maximum Allowable Load	100 SERIES PART Nos. Square	Diamond	Round	Holder
1 LB.	1 LB.	100P1	100PD1	100PR1	100PH1
2	2	100P2	100PD2	100PR2	100PH2
3	3	100P3	100PD3	100PR3	100PH3
4	4	100P4	100PD4	100PR4	100PH4
		150 SERIES PART Nos.			
2	3	150P2	150PD2	150PR2	150PH2
4	6	150P4	150PD4	150PR4	150PH4
6	9	150P6	150PD6	150PR6	150PH6
8	12	150P8	150PD8	150PR8	150PH8
10	15	150P10	150PD10	150PR10	150PH10
12	18	150P12	150PD12	150PR12	150PH12

Normal Rating @ 1/16" Defl.	Maximum Allowable Load	200 SERIES PART Nos. Square	Diamond	Round	Holder
10 LB.	20 LB.	200P10	200PD10	200PR10	200PH10
15	30	200P15	200PD15	200PR15	200PH15
20	40	200P20	200PD20	200PR20	200PH20
25	50	200P25	200PD25	200PR25	200PH25
35	70	200P35	200PD35	200PR35	200PH35
45	90	200P45	200PD45	200PR45	200PH45
		200X SERIES PART Nos.			
60	120	200XP60	200XPD60	200XPR60	200XPH60
75	120	200XP75	200XPD75	200XPR75	200XPH75
90	120	200XP90	200XPD90	200XPR90	200XPH90

Square (P) Diamond (PD) Round (PR) Holder (PH)



All Sections Shown Under Rated Loads

Series	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
100	1"	1¼"	1"	.166"	.141"	.032"	.203"	.172"	13/32"	13/16"	1 11/16"	1⅜"	.141"	5/16"	23/32"	.025"	1.414"	⅝"	1.664"
150	1½"	1¾"	1⅜"	.257"	.166"	.050"	.287"	.287"	⅝"	1¾"	2⅜"	1 15/16"	.196"	7/16"	1 1/16"	.032"	1.945"	⅞"	2.310"
200	2"	2¼"	1¾"	.391"	.196"	.058"	.471"	.471"	1"	2¼"	3"	2½"	.257"	½"	1½"	.037"	2.475"	1⅛"	2.975"
200X	2"	2¼"	1¾"	.391"	.196"	.058"	1.283"	.471"	1 13/16"	2¼"	3"	2½"	.257"	½"	2 5/16"	.037"	2.475"	1⅛"	2.975"

Figure 314. Shape, Rate of Deflection, and Maximum Loads of Lord Mountings

(b) The instruments should be so arranged that their weight is evenly distributed, thereby preventing the panel from being top or bottom heavy or one-sided.

(c) Tubing connections to all instruments should be of a flexible nature.

(d) The shock mounts should be mounted parallel to the instrument panel and aligned with the center of gravity of the entire assembly. If this is carried out it will be found that the forces which act on the center of gravity will be quickly damped out.

To determine the size of the shock-absorbers to be used, divide the total weight of the panel (complete with instruments) by the number of suspension points to be used for shock mounting. Two such units are required at each suspension point arranged in pairs. Thus, if a panel weighs 16 lbs. and it is to be suspended from four points, then eight 4-lb. shock-absorbers should be used. As a check on the size and flexibility of the shock-absorbers it should be determined that when the panel is mounted, the weight of the whole assembly will deflect the shock-absorbers at least ⅛″.

(e) The natural frequency of the entire assembly should not be more than 650 cycles per minute.

(f) Washers for the purpose of limiting movement during periods of shock or resonance, should be installed at both ends of the mounting. The washer should be equal or slightly less in diameter than the diameter of the rubber shoulders of the mounting.

Figure 314 shows the shape of the various mounts, the normal rate at 1/16″ deflection and the maximum allowable loads.

CHAPTER 33

LINK AVIATION TRAINER

The Link trainer is a mechanical device for training pilots to fly by instrument and to use the radio ranges and other modern aids to air navigation. This machine, equipped with all the latest instruments, permits a wide range of instruction including various systems of instrument landings, approaches, and take-offs, long distance reconnaissance and navigation problems, as well as standard instrument and radio range flying.

Operation

In appearance, the trainer resembles a small, hooded airplane with fuselage, wings, ailerons and the tail section. It rotates through the full 360° on a square, fixed base and has a longitudinal and lateral angle of movement approximately 30°. The motive power is a small electric motor (110 volt AC) operating a vacuum turbine, actuating a series of bellows. The air for these bellows is controlled by the stick (or wheel) and rudder through a system of valves in such a manner that the trainer banks, turns, climbs, dives, and spins in response to these controls in the same manner as an airplane.

The trainer is purposely designed to be very sensitive to the controls. One of the major faults of the pilot learning to fly by instruments is over-controlling. It has been found that once a pilot acquires the delicate touch necessary to properly fly the trainer, he experiences no difficulty in the air. This sensitivity of control, plus the fact that the trainer has no inherent stability, makes it more difficult to fly than an airplane. Consequently, even experienced instrument pilots frequently encounter difficulty at the start and it is essential to fly the trainer for thirty or sixty minutes in order to become familiar with its charac-

teristics. Once these are mastered, however, it will be found that the result will be a smoother handling of the controls when on instruments in the air.

The hooded cockpit houses the pilot's seat, aircraft controls, and lighted instrument panel. All type trainers have the regular complement of instruments used in normal instrument flying, i.e., magnetic compass, air-speed, turn and bank, vertical speed, directional gyro, artificial horizon, sensitive altimeter, and tachometer. There are also the normal radio controls, pilot's earphones, microphone, and a throttle. The instruments operate so that a given movement of the controls will bring about the corresponding change in instrument readings that would occur in actual flight.

The sensitive altimeter shows changes in altitude when trainer is in a climbing, diving or cruising attitude, which permits problems to be flown at predetermined altitudes and makes it possible to practice landings and climbs by instrument. The throttle functions in a normal manner and actuates the air speed, vertical speed, and tachometer. As the throttle is opened, the air speed increases, the vertical speed shows the proper reading in accordance with the attitude of the trainer, and the tachometer indicates proper r.p.m. When a magnetic compass is installed normally in the trainer, it functions in the same manner as the gyro compass. In order to produce northerly turning errors similar to those obtained in an airplane, a small magnet controlled by the rudder valves is mounted directly beneath the compass so with each turn of the trainer, this magnet is actuated, causing the compass to respond as it does in flight. The turn and bank, directional gyro and artificial horizon respond in a normal manner as the trainer is maneuvered by the pilot.

Rough air conditions are simulated by an automatic device for creating air bumps that can be turned on and off at the will of the instructor. The trainer is equipped with an automatic spinning mechanism that causes it to spin when stalled, in the same manner as an airplane. Recovery from the spin is effected by the proper manipulation of the controls, and all of the instruments function during the spin and recovery in a normal manner. The speed of the spin is about the same as an airplane

and sufficient to produce vertigo, so that the pilot to recover properly must follow his instruments. Icing conditions and their effect on the various instruments can be simulated.

Instructor's Desk

An instructor's desk houses the radio and intercommunicating equipment. The instructor seated at the desk issues instructions to the student in the cockpit through the two-way communications system by voice or code. The manual controls for the various radio equipment such as the radio beam signals, radio compass or flight path indicators are conveniently located on a panel in the desk, permitting the instructor to transmit the desired indications or signals to the student. Flight maps or radio range charts are located on the desk for use in conjunction with the automatic flight recorder (described later) for working problems in navigation or orientation.

Automatic Course Recorder

(Flight Log)

The equipment includes a device known as the automatic course recorder, sometimes called flight log, which moves along the desk and accurately records on a map or chart the exact course flown by the trainer. Every turn, no matter how slight, is indicated. The recorder is driven forward at a definite rate of speed so that elapsed time and distance travelled are accurate.

The device runs on three wheels, all of which are geared to a single synchronous motor. When this motor turns following the turn of the trainer, all three wheels turn. Immediate response to direction is the result, whether the turns are slight, right angles or complete. Two wheels are under power driven by two small electric motors. The third wheel is the inking pen, supplied by ink from a rotary inking pad, and traces the course flown. There are six precision ball bearings on which the three vertical spindles are mounted. There is no mechanical connection to the trainer, all connections being electric. The use of this device relieves the instructor of much responsibility, as it traces

an accurate course and indicates the slightest turn or the smallest errors in compass readings. By following the course drawn by the recorder, the instructor can control very accurately the exact signals on the radio range. When a radio problem is completed, the chart gives a graphic indication of the course flown and provides the pilot with a visual picture of the problem that is impossible to obtain by actual flying. The graph furnishes absolute proof of the problems flown and permits the student to observe his improvement from day to day. It also eliminates possible disputes between the instructor and the student as to the course flown.

Wind Drift Mechanism

The Link wind drift mechanism is an entirely self-contained "mechanical professor" which immediately and constantly solves the wind triangle automatically. It consists of an assembly of gear trains which is acted upon by trainer heading, air-speed, wind direction and velocity. The out-put, drift angle, and ground-speed are applied electrically to the recorder. The unit itself is installed in the base of the trainer.

Outside of two "coffee grinder" type wind controls at the instructor's desk, there are no visible, external controls. Thus the desk itself is clear. With the wind controls, the instructor may crank in wind at any time, from any direction he desires and at any velocity from zero up to one-half the rated cruising speed. The wind drift unit is connected mechanically to the trainer so that trainer heading is put in by means of trainer rotation and air-speed is put in by means of the air-speed condition—which is dependent on the throttle setting and/or trainer attitude.

Once the recorder has been properly synchronized with the trainer heading, the unit faithfully transmits to the recorder autosyn and drive wheels the correct drift angle and ground-speed. By turning the wind controls at the desk, the instructor may introduce a wind, the direction and velocity of which is unknown to the student pilot. By keeping a record of the headings flown by the student pilot, the instructor may, at the

conclusion of the problem, show how much the flight was affected by the unknown wind. This provides the pilot with valuable information against the day he may not have any report of wind velocity and direction while in flight. It shows him that under unknown wind conditions he must prove his position by the best known, safest means.

The instructor may accurately report the wind direction and velocity to the student, thus providing invaluable practice in making drift corrections properly.

Some rather surprising effects of wind on radio range orientation systems and beam bracketing procedures can be demonstrated with the wind drift mechanism. Almost any system works in calm air. When wind is introduced the picture changes entirely. It has been said that high winds and "bad weather" mean practically the same thing. The wind drift mechanism provides the wind for practicing under adverse conditions while the recorder chart provides permanent proof of wind effects. It is standard equipment on Type "C-3" and "C-5" trainers.

Orientation

In working radio problems, the instructor has on his desk a diagram of the desired radio range laid out to scale from the station as a center.

The instructor places the recorder at some position on the chart known to him but unknown to the pilot, and heads the recorder in the same direction as the trainer. The instructor then transmits by radio to the pilot the signal that he would receive were he flying in a similar position in relation to the radio sending station. It is the problem of the pilot to properly interpret the signals, find his location, fly to the radio beam and follow it into the cone of silence. As the recorder travels over the chart, denoting the changes of location of the ship in reference to the radio range, the instructor sends the same signals with the corresponding changes in volume and modulation that the pilot would receive were he flying on the range. Cross-country flights using regular airway maps can be simulated in

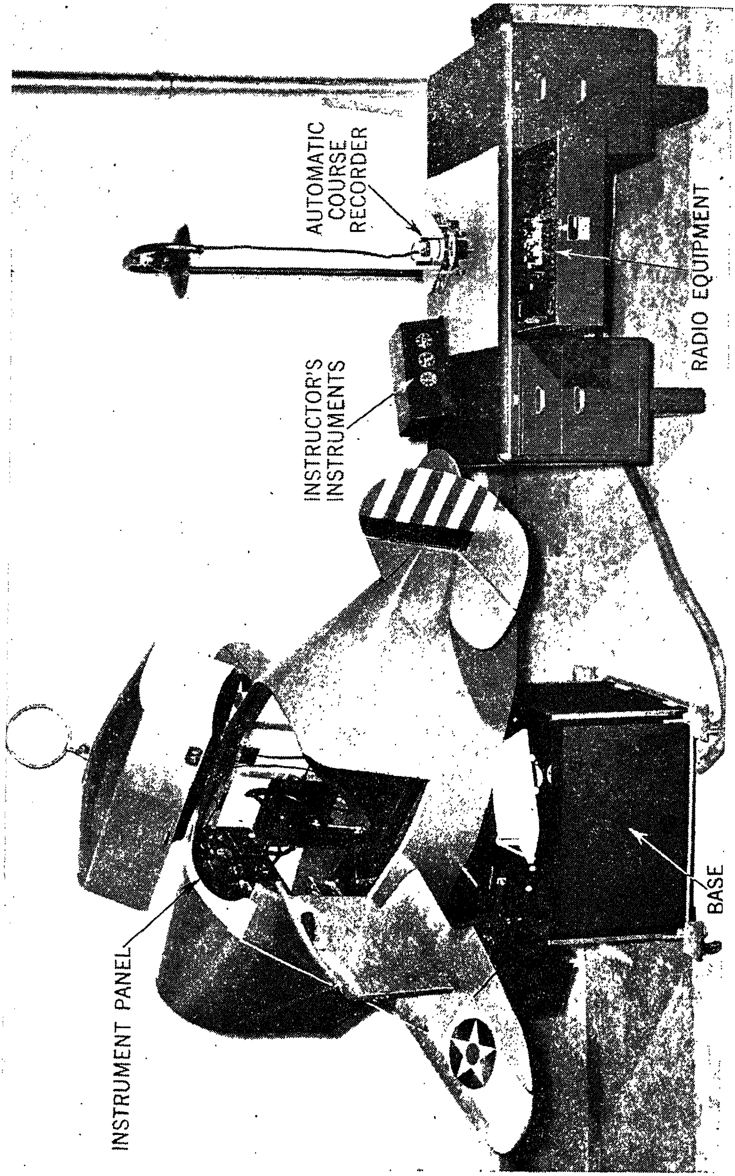


Figure 315. Link Aviation Trainer (Type C-5) and Instructor's Table
(Link Aviation Devices, Inc.)

the same manner, and various problems such as split or bent beams, cross winds, unexpected changes in weather requiring changes in courses, and other variations can be introduced. With a little ingenuity an instructor can simulate any known problem in either orientation or cross-country flying. Instrument approaches and landings using the so-called Army or Hegenberger system can be simulated by using the radio compass, marker beacons and necessary flight instruments.

Type C-5 Trainer Radio Equipment

Whereas previous Link trainer signal generators basically have been simply audio amplifiers, the "C-5" radio actually utilizes radio.

Two separate transmitters are provided, each of which has the following characteristics. The transmitting frequency ranges from 200 to 400 kc. and is readily set to the desired frequency by means of a knob. A similar control provides for control of transmitted volume to simulate various distances from the station. A selector switch provides instantaneous choice of simultaneous radio range, simulated control tower transmission (278 kc.) and radio direction finding. A suitable azimuth control is provided so that when direction finding is used the radio station may be located at any point on the chart relative to the student's "position."

The radio equipment in the trainer fuselage consists of a small 200 to 400 kc. radio receiver which must be tuned and otherwise handled in the usual manner by the student.

Two separate A-N controls are provided and five different identification calls are available.

Provision is made whereby external modulation may be applied to either or both of the transmitters. This external modulation may come either from an additional radio or from phonograph records.

This is provided so that signals from broadcast stations may be used for direction finding, or to provide range interference, also so that actual static may be introduced. Since the student is actually using radio which must be tuned and otherwise

handled correctly in order that he receive any signals at all, it is necessary to provide an emergency method of communication with him. To meet this situation, direct interphone with the student regardless of what he is doing with his radio may be established by throwing a switch.

The two transmitters may be used in various combinations such as one of them on radio range and the other one set up for direction finding. To facilitate teaching direction finding, using aural null, provision has been made so that one transmitter may be operated on a continuous 1,020-cycle note while the other transmits a 3,000-cycle note, making it easy and convenient for the student to learn the mechanics of establishing aural nulls. The two transmitters with the main control panel between them are conveniently located in the middle drawer of the desk.

The C-5 radio closely approximates regular airway radio procedure and permits the introduction of a wide range of radio navigational problems.

Explanation of Radio Operation

Figure 316 is a typical layout of a radio range station.

Radio range charts may be printed in quantities or drawn by hand on plain paper. White, or light colored wrapping paper will do.

Charts should be 24″ to 36″ square. In laying them out, a compass rose should be drawn or stamped in the middle of the blank chart. The courses of any station may then be drawn in on their proper bearings. The intersection of these courses will be at the center of the compass rose. For the first inch, or inch and one-half out from the station, the courses, or "beams," should be only the width of a fine pencil line. From this point on out, the beams should be about 3° wide. "Twilight," or bi-signal zone lines and lines of equal signal strength, should then be drawn in. Obstructions and elevations may be shown if desired but the fewer lines the chart has, the less possibility there will be of the instructor becoming confused and giving the wrong signals.

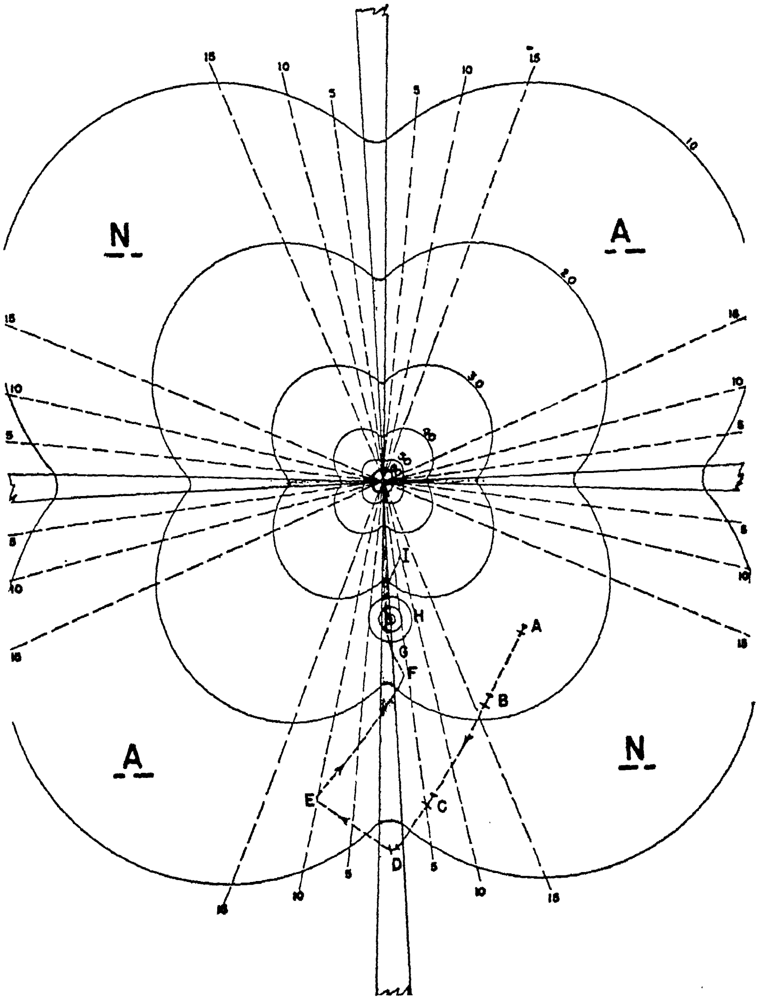


Figure 316. Typical Layout of a Radio Range Station

Large A's and N's should be stamped or drawn in the proper quadrants, and the average bisectors added if desired. The airport should be drawn in to scale and at the proper distance from the station. The scale is determined by the recorder speed. For example, a given station is 4 miles from the field: gliding speed being 120 m.p.h., it requires 2 minutes to traverse

4 miles at 120 m.p.h., and in 2 minutes the standard recorder, on 60-cycle current, will be found to travel $1\frac{3}{4}''$; therefore, in this case, the field on the chart should be $1\frac{3}{4}''$ from the station. This applies to trainers without the mechanical wind drift. For trainers with the wind drift mechanism, the recorder faithfully reproduces the tracking speed and therefore it will be found to vary.

Since signal strength patterns vary widely with the different types, the lines of equal signal strength are drawn in and numbered as an aid to the instructor in giving correct signals. It will be noted on this chart that the signal strength lines are increasingly closer together as the station is approached. It will also be noted that the line nearest the station is numbered "60." From this point to the station, the increase in signal strength is so rapid that lines representing "70," "80," and "90" would be crowded and confusing. These lines (70-80-90) should be imagined and the volume control used accordingly. If the volume control, which is also numbered from 0 to 100, is made to agree at all times with the numbered lines on the chart, the fading and building of signal strength will automatically approximate actual range signals.

The shaded portion of the beam is always an "on course" signal and requires the setting of the "A" and "N" control at zero. The dashed lines 5, 10, and 15 on the charts represent the amount to set this control "off course" according to the position of the recorder inking wheel. For example, referring to the chart (Figure 316), the student is flying southwest from theoretical position A. The volume should be set at 25 and the "A" and "N" beam shift control as far "off course" in the "N" quadrant as possible, which is 15. The student flies southwest for 2 or 3 minutes. This brings him to position B. The volume should be changed gradually to approximately 22 during this change of position. The student continues flying southwest, gradually reaching position C. During this time, the volume changes gradually to 15 and the course beam control is slowly brought from 15 through 10 to 5. At position D, the course beam control is at zero and the volume is slightly under 10. At position E, the course beam is at 10 and the volume at 15.

Heading northeast, the student returns to the beam. At point F, he has passed through the "on course" and should be given a slight N—about 3 on the beam control, which again is changed to zero, or "on course," at G.

At this point, the marker beacon is turned on, with the marker beacon volume at zero. This volume is rapidly increased to the maximum setting of 100 and then fades out again, indicating that the plane has passed over the marker at position H. At this point, the beam control is still zero and the volume is nearly 30. At position I, it will be noted that the student has run "off course" slightly, and the control settings should have been gradually and smoothly changed to 35 and 5. Continue the proper signals in the same manner throughout the problem. The "cone of silence" at the station is obtained by turning the volume down and returning it again to full volume in from one to ten seconds' time, depending on the student's "altitude." In fading out the signal to simulate the "cone," the signals will sound more natural if the rate of fade is in proportion to the length of time of the "cone of silence." A small "cone" requires a quick fade.

Attention is called to the fact that the signals at a given distance from the station are considerably louder when entirely "off course," midway between two beams, than when actually on the beam.

Twilight zones, multiple courses, etc., may be drawn on the map and simulated by manipulation of the controls. At intervals, a standard weather broadcast should be made. The student should be required to "report in" and all control tower routine should be practiced.

The large chart (Figure 318) shows a combination of radio range stations such as might be found on a typical cross-country flight. By using a chart of this nature cross-country problems may be simulated with extreme accuracy, the trainer equipment being so arranged that it is possible to shift from one radio range station to another at will. The instructor technique in the supervision of cross-country problems is similar to that previously described, each station being taken up separately as the student pilot indicates his desire to tune in on it. Such

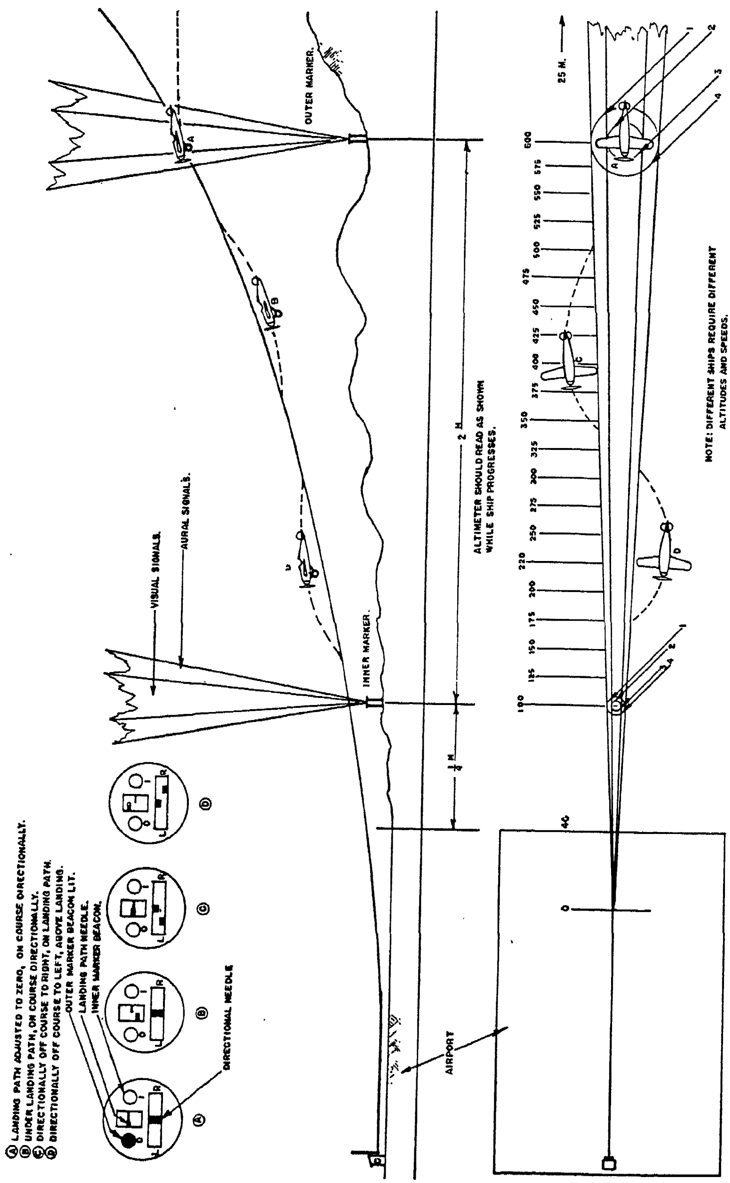


Figure 317. Landing Path Diagram

problems may be made more interesting by periodic announcements of various weather conditions at different points as indicated.

Flight Path Landing System

The flight path system incorporates the use of a directional and glide path indicator. The instructor watches the progress of the flight log and the altimeter and signals the student whether or not he is "on course."

Marker Beacons. In the flight-path system there are two marker beacons employed, one—the inner marker—and the other—the outer marker. These beacons are located in line with the runway to be used. The directional beam sent from the station at the end of the runway passes directly over these two beacons. The inner beacon is located approximately a quarter mile from the end of the field, and the outer beacon is located two miles from the inner beacon. These distances may be varied upon installation to suit the particular requirements of the ship being used and also to suit the terrain.

Landing Procedure. The student coming in toward the station picks up the directional signal as he gets approximately 25 miles from the field. The instructor gives him this signal by switching on the directional indicator switch which is located in the small control box to the left of the radio in the desk. From the time the directional beam is picked up, until the outer marker beacon is passed over, the only signal the student receives is the directional signal which is given by the instructor by means of the "E" and "T" beam shift control. When the beam shift control is on center or zero, the indicator in the cockpit will be at zero. "OFF COURSE" is shown in a similar manner. When more sensitivity is wanted, the instructor can regulate the course indicator deflection control to give the needle of the directional indicator more "kick." The direction of "kick" is governed by the way the instructor has the "E" and "T" course beam selector off-center.

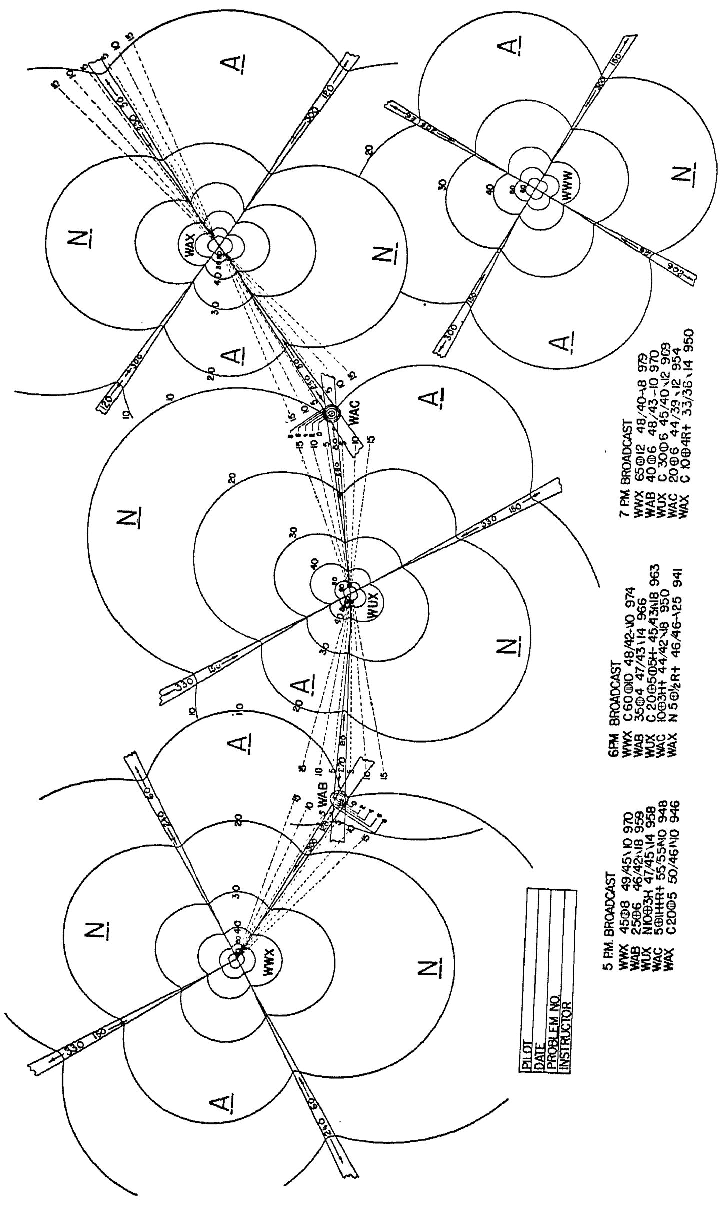


Figure 318. Radio Range Chart Cross Country

The student starts to receive the outer beacon signals at point 1. The instructor gives him the aural signal by switching the pointer of the beacon selector to "outer" and gradually increasing the volume. As the instructor continues to increase the aural volume, the volume control closes the circuit to the visual marker at 2. When the student receives the visual signal, he immediately sets his landing path needle to zero by means of the volume control in the cockpit. He then immediately starts his descent. As can be seen from Figure 317, the student should be at definite altitudes as he progresses along his course toward the landing field following the directional beam. The instructor notes the altitude on the remote reading instrument as the flight log progresses, and if the rate of descent is too great, he moves the glide path indicator control so that the needle will be below zero. This indicates to the student that he is below the beam and vice versa if above. The control for the glide path indicator is on the control box to the left of the radio.

As the inner beacon is approached and passed over, different signals are given by switching the beacon selector to "inner." The signals are given by the instructor in the same manner as the signals for the outer beacon were given at point 2. As the student leaves the beacon range, the instructor starts to turn back the volume controls to the beacons, automatically shutting off the visual signals as he passes point 3. The aural signals will gradually diminish until at point 4 these are gone also. After that the marker beacon selector switch can be switched to "off."

The student passes over the inner beacon and prepares for a landing. During this time the instructor should be constantly on the alert, watching the progress of the recorder and the altitude flown and giving the proper indications to the student. It should be noted that on any bent beam system of instrument landing, the glide path indicator at the moment of contact with the ground when nearly at the sending station, moves abruptly to the top of the scale due to increased field intensity. When the altimeter reads zero, the student should raise the hood, and if the flight log is at the proper point on the runway, the landing is a success.

CHAPTER 34

INSTRUMENT FLYING TRAINING

Instrument flying means flying entirely by the indications of the instruments without any external references. It means that with the full knowledge of the use of the instruments and the ability to correctly control the aircraft from the indications, safe flights may be made in adverse weather.

The late Howard Stark visualized the need for a system of instrument flying instruction and was one of the first to present a book toward this end.[1]

It is by the courteous consent of the authors that the following data are presented.

The 1–2–3 System

In actual practice the pilot reads the rate instruments in the 1–2–3 sequence, the order in which they are read being:

1. The Turn Indicator.
2. The Ball Bank Indicator.
3. The Air-Speed and Rate of Climb Indicators.

In the same way the controls of the airplane are operated as follows:

1. Rudder Control.
2. Aileron Control.
3. Elevator and Throttle Control.

Thus we find the relation between the controls and the instruments as:

1.	Rudder Control	Turn Indicator
2.	Aileron Control	Ball Bank Indicator
3.	Elevator Control	Air-speed Indicator
	Throttle Control	Rate of Climb Indicator

[1] Lieutenant Commander P. V. H. Weems and Charles A. Zweng, acquiring the rights to Howard Stark's book, have incorporated the basic idea of the Howard Stark system in their excellent book "Instrument Flying."

Straight Flight

In order to maintain level flight, the pilot applies the 1–2–3 order as follows:

1. Center the turn indicator with the rudder only.
2. Keep the ball bank indicator centered with the ailerons.
3. Keep the air-speed indicator at the desired cruising speed with the elevators only. Keep the rate of climb indicator on zero with the throttle only.

Turning

1. Use the rudder to start the turn while watching the rate of turn indicator for the desired rate of turn.
2. At the same time keep the ball bank indicator centered, using the ailerons.
3. Keep the climb indicator centered, using the elevators. Watch the air-speed indicator for proper speed.

There must be coordination in the turn. Do not depend on the compass while turning; rely on the turn indicator hand and time the turn.

Lessons under the 1–2–3 Order

Rules. The 1-2-3 order has the advantage of being both simple and definite. It definitely associates each instrument with its proper control. It is understandable, easy to remember and easy to use, and it applies equally well to all desired maneuvers of the airplane.

Basic instrument flying training requires a different kind of skill than that in contact flying. This skill consists of entirely distinct habits of perception and reaction, which are formed by other exercises. Skill in contact flying does not aid the student in basic instrument flying training. The "feel of the ship" habits of contact flying are even harmful and must be neutralized whenever the beginner is on instruments.

The student of instrument flying should try to form four important habits as soon as possible. These are:

1. Frequent and accurate observation of certain instruments.
2. Operation of controls by automatic or reflex action to produce or maintain the proper instrument readings for particular maneuvers.
3. Disregard of sensations received otherwise than through instruments.
4. Relaxation, confidence, and precision.

The routine of each lesson should comprise two phases:

1. Performance of every maneuver previously learned at least once.
2. Improvement of one or two of these, or the learning of one or two new ones.

The student must cultivate familiarity with the instruments. He must learn the combination readings produced by correct performance of prescribed maneuvers. There is a tendency for beginners to rivet attention on one instrument to the exclusion of the others. The 1–2–3 order overcomes this by making the student form the habit of reading and controlling all the essential instruments frequently.

Basic Training. In basic training the turn indicator is always first, the ball bank second, and the air-speed (and rate of climb) third. After the 1–2–3 habit is well fixed, the student may improve it by:

1. Learning to start an instrument in the right direction, complete the cycle, and get back to the first instrument before its index is at the desired location.
2. Learning to read and operate two instruments simultaneously, as turn indicator and ball bank, or turn indicator and rate of climb.
3. Coordinating all instruments as nearly simultaneously as possible.

The maneuvers of basic training are listed below. They should invariably be learned in the order indicated.

1. Straight and level.
2. Straight climb.
3. Straight glide.
   (a) Power off.
   (b) Power on.
4. Standard turn, left and right.
5. Timed turns.
6. Double rate turns.
7. Stalls.
   (a) Power off.
   (b) Power on.
8. Recovery from abnormal flight attitudes.
9. Standard spiral climb.

Prior to flight, each maneuver to be learned should be explained by the air instructor, as in the following example:

MANEUVER. Straight and level.

PURPOSE. Familiarization with airplane instrument control.

INSTRUMENTS AND THEIR POSITIONS

Turn Indicator	Centered
Ball Bank	Centered
Rate of Climb	Centered
Air-Speed	Cruising

The instructor should emphasize the errors usually made by beginners.

Remarks: During his first lesson the student may be required to control the rudder only, for about ten minutes before being given the stick. He may also be reminded of the relatively decreased importance of the ball bank indicator in straight-line flight. In the air this may be proved to him by the rolling exercise.

Lesson 1. Straight and Level

Preparation. On all flights make sure that your parachute fits properly and is entirely comfortable. See that your safety belt is fastened but not too tightly. Get comfortably seated in the airplane before closing the hood. See that your altimeter is

properly set. Now, talk to your instructor through the microphone and be sure that his voice comes through clearly, and that you understand his instructions. Study carefully each flight assignment handed to you. If there is any point in this assignment not clearly understood, discuss it thoroughly with your instructor before take-off.

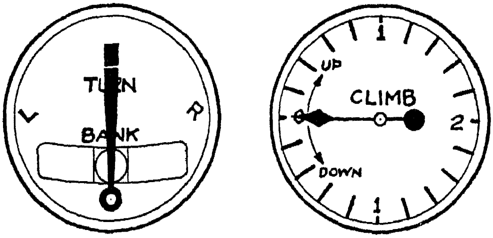


Figure 319. Straight and Level Flight

Actual Work. On this first flight, try to maintain the airplane in straight and level flight. Remember:

1. The turn indicator is controlled by the *rudder.*
2. The ball bank indicator is controlled by the *ailerons.*
3. The air-speed indicator is controlled by the *elevators* and the rate of climb by the *throttle.*

Also keep in mind:

1. When you keep the turn indicator centered with the rudder, you are flying straight.
2. When you keep the ball centered with the ailerons you are flying level laterally.
3. When you keep the air-speed at the proper cruising setting with the elevators, you are flying level longitudinally. When you keep the climb indicator at zero with the throttle, you are holding your altitude.

The 1–2–3 system must be followed carefully and each instrument controlled as follows and in the order given:

1. Rudder controls the turn indicator.
2. Ailerons control the ball.
3. Elevators control the air-speed, and the throttle controls the climb indicator.

Relax and be comfortable. On the first flight, concentrate on the turn indicator and ball, not paying too much attention to the air-speed and climb indicator. The important thing is to keep the turn indicator centered and fly straight and the ball centered and fly level. You may glance at the other instruments occasionally, but the important thing on the first lesson and every lesson is to keep the turn indicator centered with the rudder. Keep the ball centered with the ailerons. Relax—don't try too hard! Center the turn indicator and center the ball (Figure 319).

Lesson 2. Normal Climb

The purpose of this maneuver (Figure 320) is to develop control of air-speed (with rate of climb as a check) under climbing conditions, to gain altitude rapidly for practice, and to provide some rough air practice.

INSTRUMENTS AND THEIR POSITIONS

Turn Indicator	Centered (in first practice)
Ball Bank	Centered
Air-Speed	Steady at proper speed for particular airplane
Rate of Climb	Determined by throttle setting
Throttle	Normal for climb

In a climb the air-speed indicator is consulted to make sure that the actual air-speed is never less than the rated climbing speed of the airplane. As a general procedure, it is best not to try to climb too fast.

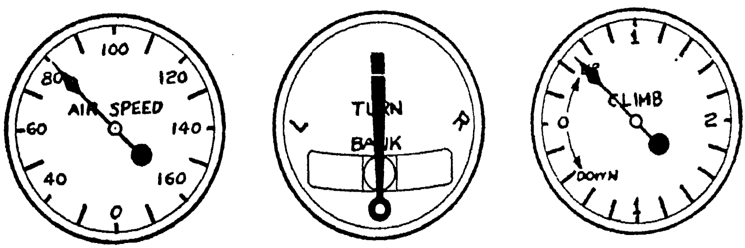


Figure 320. Climb

For any airplane the maximum safe rate of climb, at sea level, as shown by the climb indicator is determined by the reserve of engine horsepower, in excess of that required for level flight. This is termed "initial rate of climb." Since the safe rate of climb is a function of the altitude, air-speed, and gross weight of the airplane, several flight conditions arise which are subject to so much variation, even during a single trip, that the climb indicator, as already stated, is not a definite guide during either climb or glide. It simply shows the rate at which the airplane is going up or down. The information given by the air-speed indicator is most important for safe control.

The climb indicator is subject to a slight lag, but when the pilot has sufficient practice in using it, this lag will not be confusing.

Since the climb indicator functions as a result of changing atmospheric pressure, it may show abnormally high or low rates of climb or glide momentarily during flight in storm areas where rapidly rising or falling air currents are encountered. For this reason the air-speed indicator should be watched carefully and maintained at a safe cruising speed.

The climb should be continued to a point at least 1,000 feet above any unknown obstacles on the course, and in rough air it is well to go even higher. The throttle should be set and the stabilizer adjusted in order that the air-speed may be kept constant without pressure on the stick.

Lesson 3. Straight Glide, Power Off (On)

The purpose of this maneuver (Figure 321) is for perfection of air-speed (and rate of climb indicator) control.

INSTRUMENTS AND THEIR POSITIONS

Turn Indicator	Centered
Ball Bank	Centered
Air-Speed	As in contact flying glide
Rate of Climb Indicator......	Normal for particular airplane
Throttle	Completely closed

To execute a glide with the power on, the motor is slowed down and the elevators are used as necessary to keep the air-

speed indicator at the desired air-speed (usually the rated climbing speed).

If a slow rate of descent is desired, the climb indicator should be consulted as a guide to this rate. Sufficient motor power should be used to hold the desired rate of descent, and the proper air-speed should be maintained.

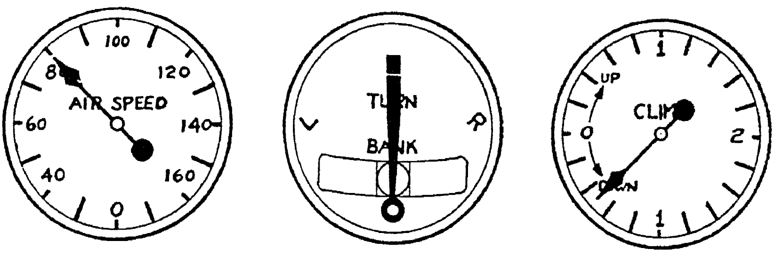


Figure 321. Glide

In either a straight glide or a straight climb, at a uniform speed, the compass will soon stop oscillating and give a reliable indication of direction.

The glide is an important maneuver to practice for the approach to lower levels and the ground. Straight glides should be made as far as possible under actual conditions, but the practice should include glides near the stalling point as well as steep glides.

Power Glide and Let-Down Procedure. Procedure on let-down from level flight is as follows:

1. Use throttle first, then stabilizer.
2. Reduce throttle as needed to bring rate of descent slowly to desired position at 500 feet per minute.
3. Maintain the air-speed at the desired rate of 100 m.p.h. with the elevators.
4. With the rate of descent at 500 feet per minute and the air-speed at 100 m.p.h., reset the stabilizer to relieve all elevator pressure, and the airplane will balance hands off.

Center the needle and center the ball (Figure 319). Reference to the air-speed before reference to the rate of climb is

absolutely necessary when bringing the airplane to level flight condition after climb or let-down.

Constant reference to the turn needle and ball, the air-speed and the rate of climb in the order named will maintain the 1–2–3 system. One important point to remember is that air-speed must be near the proper setting before rate of climb is referred to. Center the needle and center the ball.

Another important point is that all throttle changes must be made slowly but firmly. This is especially true when opening the throttle, as opening the throttle rapidly upsets the balance of the airplane and disturbs the instruments to such an extent that they require much more attention than if the throttle were opened easily and smoothly.

Remember when starting let-down, throttle back first and then stabilizer nose up. When coming to level flight after let-down, stabilizer nose down first, then throttle forward. Close throttle easily and smoothly to let-down; open throttle easily and smoothly after let-down.

When reducing throttle the nose tends to drop, the airplane dives, and air-speed builds up. When opening throttle the nose tends to come up, the airplane climbs, and the air-speed falls off. It follows, therefore, that when letting down and reducing throttle, you must roll your stabilizer nose up as needed when the nose tends to drop. Also, when leveling off after let-down, roll the stabilizer nose down before opening throttle easily and smoothly.

Caution: In letting down, use throttle first and then stabilizer. Stabilize again as needed.

In leveling off after climb or let-down, maintain your proper air-speed with the elevators and set rate of climb at zero slowly with the throttle. Then relieve pressure on the stick or elevators by using the stabilizer as needed to establish the rate of climb at zero. Make all throttle changes slowly and smoothly.

When flying in rough air, the turn needle may be deflected off center one or two needle widths. In order to stay on course the needle must be ruddered an equal amount to the other side and then centered. Maintaining a straight course by simply bringing the needle back to the center should not be attempted.

To prove that the airplane may be held to a close course in turbulent air, try the following operation in smooth air:

Note your compass heading, and keep the ball centered with ailerons while you rudder the needle one width to the right and then one width to the left. Repeat the operation of ruddering the needle one width to the right and then to the left for 10 or 15 seconds without looking at the compass, then center the needle and center the ball. You will note your compass heading has not changed over 5°, if this much, thereby proving it is possible to hold a close average compass heading in rough air.

Caution: Remember that when the turn needle is deflected to the right, the needle should be ruddered back to the left an equal amount and then centered.

Lesson 4. Standard Turn, Left (Right)

The purpose of this maneuver (Figure 322) is to secure practice against turn-tightening, a prerequisite for timed turns. Every part of turning movement can be done by 1–2–3 order:

1. Start the turn by using the rudder until the turn indicator shows the desired rate of turn. (The sensitive instrument may oscillate somewhat, and thus require an approximate or average reading.)
2. Keep the ball bank indicator centered, using ailerons to maintain the correct lateral position and to prevent skidding or slipping.
3. Keep the climb indicator centered, using elevators to be sure of making a level turn. Check the air-speed indicator to be sure of the proper air-speed.

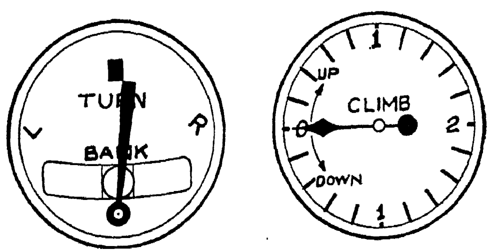


Figure 322. Turn

Coordination. The sharp turn is started by using the rudder until the turn indicator marks the desired rate of turn, and the ailerons are used as needed to maintain the correct bank. As the turn progresses, the rudder is moved as required to keep the turn indicator hand at the desired point; the ailerons are used as needed to maintain the correct bank; and the elevators are used to keep the climb indicator centered. It is evident that proper coordination is essential.

Number 1 and Number 2 must be done in very close coordination. The use of too much rudder without the coordination of the ailerons will cause skidding.

The compass is not a reliable index of turn while the turn is in progress. The position of the turn indicator hand will indicate the rate of turn, and the amount of turn can be determined approximately by timing.

In instrument flying by the 1–2–3 order there is no instrument which will give the pilot the amount of bank. The turn indicator, however, will show the rate of turn, while the ball bank indicator will show how to hold the ailerons to maintain the correct bank for any turn. For the normal two-minute turn, the correct degree of bank is approximately 15°; therefore, indirectly, the turn indicator shows the approximate amount of bank.

It will be apparent that for any given rate of turn and degree of bank the various controls will be held in exactly the same positions as would be the case if the same rate of turn and degree of bank were started and controlled in normal flight with outside visibility.

Instruments Off-Center. If the ball bank indicator or the climb indicator or both do get off center and the pilot is not sure of the turn, he should immediately return to straight, level flight by the 1–2–3 order. He will then be in a position to start another turn.

After recovering from a turn and checking with the compass, the pilot may find that the airplane is not yet on the desired course. In such a case, the airplane is put on the proper course by making a slow turn.

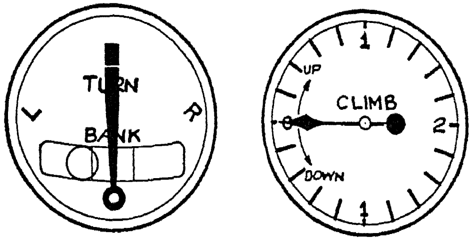


Figure 323. Left Wing Low

Careless Flying. If a pilot is maintaining straight flight, but with the left wing low, the condition will be indicated by the turn indicator being centered but the ball being to the left of the center. (See Figure 323.) Careless flying of this type is a common fault with students and should be corrected at once by keeping the turn indicator centered and centering the ball.

Lesson 5. 90°, 180°, 360° Turns

90° Turn, Left (Right). The 90° turn gives the student additional protection against turn-tightening, prepares him for double-rate turns, and helps him to gain proficiency in coordination.

The position of the instruments is the same as in standard turn from level flight, but the time element is an important additional factor. Thirty seconds is required for this maneuver. Timing is begun as the turn starts, and recovering from the turn should be started at the expiration of the time.

180° Turn, Left (Right). The 180° turn offers no real difficulty after proficiency has been attained in 90° turns. It is performed exactly like the smaller turn except that the time is extended to one minute. (In either case, the time should be determined by the use of the clock.) This turn is made by holding the turn indicator exactly on the two-minute turn position and then straightening up. The error in this maneuver should be within 10°.

360° Turn, Left (Right). These turns are made exactly like the 180° turns, with the exception that the turn is held for two minutes instead of one.

Typical Turning Errors

Errors	Remedies
1. Turn-tightening (turn indicator pointer creeps farther away from center, ball creeps to same side as pointer. Rate of climb shows descent, air speed reads high to very high.)	Return to 1-2-3 order, and try again.
2. Overturning, underturning, and lack of coordination.	Practice.
3. Zooming on recovery.	Slight forward pressure is applied to stick as turn indicator pointer approaches center.

General Procedure. When entering a turn, lead with the rudder, using sufficient pressure to hold the turn indicator in the proper position. Follow with enough aileron to keep the ball centered. Keep the pressure balanced between top and bottom rudder.

When going into a bank and holding it, give close attention to the turn and bank and rate of climb indicators, keeping the rate of climb level in order to hold altitude.

When returning to straight flight, apply pressure with the top rudder, center the turn indicator, and follow simultaneously with enough aileron to center the ball. At this stage it will be difficult to keep the turn indicator centered, because on straightening up after the turn there will be a sensation that the plane is turning in the opposite direction.

Lesson 6. Double-Rate Turn, Left (Right)

The practice of the double-rate turn is another protection against turn-tightening and is also a prerequisite to recovery from spirals.

Instruments and Their Positions

Turn Indicator	Spaced apart from the center mark by one width of the pointer
Ball Bank	Centered
Rate of Climb	Centered
Air-Speed	Cruising speed or slightly below

Lead with the rudder and follow with the aileron on all turn maneuvers. Remember that the position of the turn indicator is controlled with the feet and of the ball with the ailerons.

The student should practice these turns without letting the ball get on the low side, air-speed get above cruising, turn indicator creep away from center, or zooming take place on recovery.

Lesson 7. Stalls, Power Off (On)

This maneuver gives the student practice in control of the turn indicator and ball just before stalling. It also prepares him to avoid a zoom after recovery.

INSTRUMENTS AND THEIR POSITIONS

Turn Indicator	Centered
Ball Bank	Centered
Air-Speed .... Rate of Climb	After closing throttle as directed by instructor the rate of climb is held centered and air-speed allowed to reduce until the airplane "falls off." Disregarding rate of climb, the air-speed is brought above normal gliding speed, then gradually reduced to normal before opening throttle.

In recovering from a stall, the important thing is to recover speed by pushing forward on the stick, easing off as soon as air-speed begins to show a build up. Concentrate on the 1–2–3 system; center the needle, center the ball, center the climb indicator, and control the air-speed indicator.

Lesson 8. Recovery from Spiral or Spin

The instructor takes the controls and, with throttle normal for cruising, puts the turn indicator over to its limit, ball about halfway between center and the same side, and air-speed about 30 m.p.h. above cruising. He then gives the command, "O.K.—straight and level." The student then restores the instruments to normal, manipulating the controls in the 1–2–3 order.

This maneuver is good practice for the student to overcome turn-tightening and zooming after recovery. The usual errors are extreme over-controlling of rudder and ailerons; also, zooming after recovery. Practice of double-rate turns will aid the student in overcontrolling. To prevent zooming, the student should maintain a prolonged forward pressure on the stick with the gradual reduction of air-speed.

Lesson 9. Standard Spiral Climb and Descent

The spiral climb is useful for climbing in restricted areas. A spiral is simply the combination of a turn with a glide or a climb. In a spiral, all of the instruments are affected; whereas in the movements previously described, some are undisturbed. In the spiral climb the instrument indications and necessary procedure are as follows:

1. Turn indicator shows the rate and direction of the turn. Keep the hand at a fixed distance off center to maintain rate of turn.
2. Ball bank indicator shows the correct bank of the airplane. Keep the ball centered.
3. Air-speed indicator shows the climbing speed. Maintain a safe climbing speed.
4. Climb indicator shows the rate at which the airplane is ascending. This may be disregarded.
5. Altimeter shows the increased altitude. If the spiral is made for the purpose of gaining altitude, the altimeter shows when to level off. Otherwise, it may be disregarded.
6. Compass shows the total turn. This must be disregarded during the spiral. Check reading when the spiral is completed and the compass has stopped oscillating.

It will be seen that in the upward spiral only three of the instruments require careful attention and that they are used in the 1–2–3 order.

The climb is usually started at cruising speed, and the rate of climb may at first be quite rapid. As the climb proceeds,

however, the air-speed will decrease and should be held at a safe climbing speed with the elevators and the climb indicator maintained at the desired climbing rate with the throttle. *Watch the air-speed and do not let it fall too low.* After an altitude of 1,000 feet is reached, the direction of turn is reversed, and the climb continues for another 1,000 feet, then into straight and level by the 1–2–3 system.

The Downward Spiral. The spiral glide is made in the same way as the spiral climb, except that the engine speed is reduced. The pilot must watch the altimeter and stop the spiral at a minimum safe altitude.

The spiral may be started in level flight with a turn, or it may be started by making a turn when the airplane is already in a climb or in a glide. It is always important, however, to refer to the instruments in the 1–2–3 order to manipulate the controls in this same order.

The spiral requires practice. It is in the spiral, and especially in the downward spiral, that the pilot is most apt to get into trouble when flying by instruments. The fact that all the instruments are in motion at once is very confusing, unless the pilot knows just what these movements mean and which of these instruments require attention.

It is here that the 1–2–3 order is most useful. Every reference to the instruments and every operation of the controls should be made in the following manner:

1. Keep the turn indicator at the desired rate of turn.
2. Keep the ball bank indicator centered.
3. Keep the air-speed indicator at the gliding speed.

Lesson 10. Clear Weather Practice

The following plan is suggested as suitable for practice in the 1–2–3 order, either with or without an instructor. It is assumed that the student is already a competent pilot for ordinary flying.

Under no circumstances should the student attempt any practice "under the hood" until he has had a thorough pre-

liminary training. He should be free to get his bearings and control the airplane by the ordinary methods, if necessary, while at the same time he can observe the instruments and see just how they react to the several motions of the airplane.

Use of the Instruments. The practice here recommended is confined to the rate instruments. Their correct arrangement is as follows: The turn and bank indicator in the center, air-speed indicator at the left, and the climb indicator at the right.

The pilot should start by centering his attention on the instruments one at a time, always bearing in mind that:

Turn indicator directs the rudder control.
Ball bank indicator corresponds to ailerons.

Air-speed and climb indicator correspond to elevators. Separate use of the controls and careful observation of the effect of each upon its corresponding instrument will help the pilot to understand more clearly why these relations exist.

Repeated and carefully planned practice in making a turn and in recovery from a turn will soon demonstrate to the pilot, to his own complete satisfaction, that the only way to keep the airplane correctly banked is to carry out No. 1 and No. 2 in very close coordination. He should, however, always make it a rule to start No. 1 before he starts No. 2.

Only when the student is thoroughly familiar with the use of the turn indicator and the bank indicator is it time to experiment with the air-speed indicator and the climb indicator. At first it will be well to maintain straight flight, while the airplane is put into a climb or a glide by using the elevators only. The effect of the elevator control upon both the climb indicator and the air-speed indicator should be carefully observed. It will be noted that there is considerable lag in both of these instruments.

At first, in the climb, the air-speed should be kept at the rated climbing speed. Presently, however, just to see what will happen, the pilot should take the climb at such a steep angle that the airspeed will fall below the stalling speed. It will soon be noted that in any of these movements, particularly

in a whipstall, the air-speed indicator gives more useful information than the climb indicator.

The whipstall is a complete stall in which the airplane becomes entirely unmanageable for lack of speed. It will occur when the airplane is in too steep a climb. When the airplane stalls from a climbing position, the nose will whip downward at once, due to the weight of the motors. The whipstall demonstrates that the climb indicator is quite useless in very rough air, as in a line squall.

Practice Exercises. Next should come practice in the same maneuvers with variations in engine speed. Greater engine speed will, of course, make possible a climb at somewhat higher rate, as marked by the climb indicator; while reduced engine speed, or power off entirely, in a steep climb can result in nothing but a whipstall. Practice in the whipstall is well worth while.

This kind of experiment will convince the pilot (1) that the air-speed indicator must always be consulted to determine whether or not the airplane is moving at a safe rate of speed, and (2) that the climb indicator is most serviceable as a guide in maintaining level flight at a uniform elevation above the ground. It is now time to practice maneuvers that will combine the use of all of these instruments.

The pilot should practice returning to straight, level flight from a steep spiral by the 1–2–3 order. After all, the ability to recover from any awkward position is the most important part of the training of a pilot, for even the most competent pilot may occasionally, in a moment of inattention, allow the airplane to get out of control.

All the practice outlined above should be performed with the pilot seated so that he has full outside vision and can thus save the situation should he become confused. Seated in this manner, he will also be able to check the instrument readings against the observed motions of the airplane.

After a suitable practice in the various maneuvers and in recovery from whipstalls and spirals, both upward and downward, slow and fast, the pilot will be ready for a real test of

what he has learned. Now is the time for him to throw the airplane entirely out of control, as in a tailspin. Let him see if he has acquired sufficient knowledge of and confidence in the instruments to enable him to recover by their guidance alone. If he can do this successfully on several attempts, then and only then is he ready for practice "under the hood."

General Remarks. Always remember that your compass will not indicate your correct heading unless the turn indicator is centered and has been for at least six seconds. In other words, the airplane must be flying straight (turn indicator centered); then and only then will your compass indicate the actual heading of the airplane.

Since the compass magnetic element is pivoted on a bearing and pendulous, the compass bowl may be tilted 10° to 20° before the compass reading becomes seriously affected. Therefore, in straight flight, one wing may be low, and the ball indicator off center, and the compass might still indicate the correct heading. When the tilt of the compass is greater than about 20°, the compass will not indicate the correct heading. With the airplane flying straight and level (not diving or climbing), it follows that the compass card is level and free, and when free to move on its pivot will naturally indicate the correct heading of the airplane.

Lesson 11. The Airplane Out of Control

As a general rule the airplane will get out of control only in a turn, or, more especially, in a downward spiral. When such a condition arises, two things must be done—(1) stop the turn, and (2) level off. If the pilot tries to level off first, he will only succeed in tightening the turn, and the result will be a tight spiral. If, however, the turn is stopped first, the airplane will be going in a straight line, although perhaps in some unknown direction. For the purpose of leveling off and centering the other instruments, it does not matter in which direction the airplane is headed, as long as the turn is stopped.

The operation of leveling off is just as important as that of stopping the turn. It should not be delayed until the turn

is entirely stopped but should be begun as soon as the turning movement is entirely under control. The important consideration is that, if the leveling off operation is begun first, it may become more difficult or even impossible to stop the turn.

The turn indicator is logically the first instrument to be consulted and should be corrected by the use of the rudder in any circumstances that may arise. There need never be any confusion if the instruments are read and the controls manipulated in the 1–2–3 order.

The pilot should practice spirals, both upward and downward, at standard rate of turn and rate of climb or glide. He must make sure of his ability to go into any spiral and to return from any spiral to straight and level flight, solely by guidance by the instruments.

This training should continue until the pilot is able to tell from the readings of the several instruments whether the airplane, temporarily out of control, has gone into a spiral dive. He must be able to recover promptly from this position to straight and level flight.

CHAPTER 35

RADIUM PAINTING

The radium painting of aircraft instrument dials, hands, and indicators may be performed by anyone if proper precautions are taken.

(a) The hands must be free of cuts or sores to avoid infection.

(b) The mixing of the radium powder with the adhesive and thinner should be done in still air to prevent the inhaling of the powder.

(c) The face, especially the mouth and eyes, should not be touched with the hands.

(d) Remove radium paint from the hands by scrubbing with thinner. Then observe the hands in a dark room for 10 minutes. Ordinary fluorescent paint will lose its glow in that time; radium paint will still show.

Composition

Radium Luminous Paint #22 M is very small in radium concentration, about one part in 60 million being radium, the remainder of the powder consisting of zinc sulphide, a fluorescent material.

Preparing the Surface

Whenever possible, it is recommended that the surface to be coated with radium paint should be roughed with fine sandpaper. Apply one or two coats of zinc white as a base coat; do this even where sanding is not practicable. Let the zinc white dry from 1 to 4 hours till hard, depending on atmospheric conditions, before applying the radium paint.

Painting

The paint to be applied is mixed from the powdered #22 M material, to which is added adhesive cement, and a thinner for the cement, to give the mixture a sticky consistency similar to pancake batter, not to liquid.

To apply the paint, use a #00 red sable brush. The brush should be dipped into the mixture and rotated, forming a small ball. The paint must be *placed* in position in small daubs, since it cannot be flowed over a surface like paint.

A protective lacquer to prevent abrasion and weathering should be used to cover the radium paint.

The luminosity may be checked in a dark room. Allow at least 10 minutes for the eyes to become accustomed to the darkness. The radium paint should glow distinctly.

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